Development aid and public investment programs in Sub-Sahara Africa

Modeling aid-financed investment in infrastructure and education and estimating relevant parameters

Dissertation

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Vorgelegt von: Hannah Schürenberg-Frosch
Geburtsort: Duisburg

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Erstgutachter: Prof. Dr. Volker Clausen

Zweitgutachter: Prof. Dr. Jan Willem Gunning

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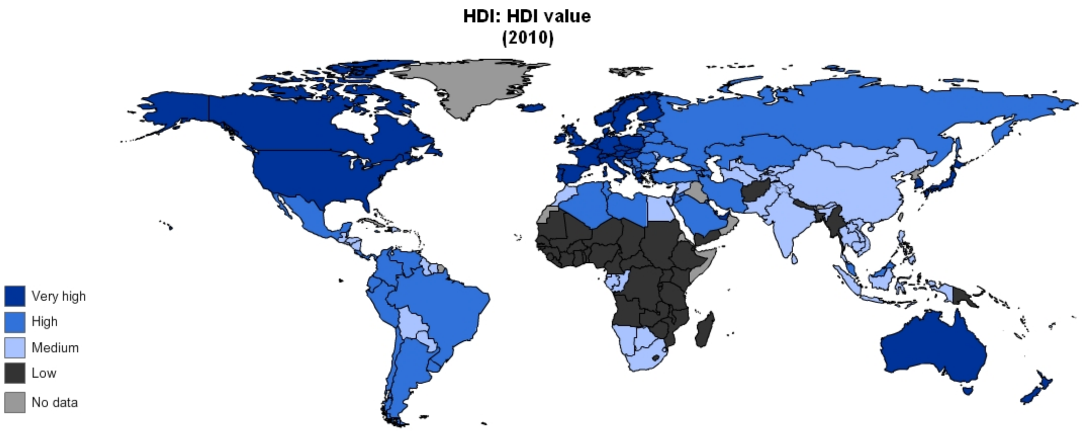
1. Motivation

After more than sixty years of international cooperation towards development and extensive developmental assistance, the African continent is still in many aspects being left behind by the rest of the world. From an economic, political, humanitarian and ecological perspective, Sub-Saharan Africa lags behind the other regions of the globe. Out of forty-two countries that have been classified as having the lowest scores in the Human Development Indicators for 2010, thirty-five are in Africa. In other words, a mere twelve out of fifty-two African states are not listed among the least developed countries in the world.[1]

Figure 1.1.: World map of the Human Development Index in 2010



Source: `http://hdr.undp.org/en/statistics/data/hd_map/`

The international community has taken important steps in fighting extreme poverty and famine, low levels of education and sanitation, as well as serious diseases and epidemics. A joint attempt to foster development on the global scale is documented in the Millennium Development Goals (MDG). Regardless for many countries having managed to substantial progress in achieving the aforementioned goals, the 2010 MDG report continuously identified a number of targets that prove to be out of reach for Sub-Saharan Africa. Still more than half of the Sub-Saharan population was living on less than $1.25 a day in 2005, which demonstrates a very slow reduction since 1990. The young population of the region appears to suffer most from this situation of extreme poverty: Sub-Saharan Africa has the highest incidence of child undernourishment, the lowest school enrollment rates, and the highest child mortality among all of the developing countries. Access to

[1]Five African countries are not included in the Index due to incomplete and missing data.

sanitation and vital medical care are particularly scarce in the rural areas of the continent.

After roughly half a century of independence, many African people are still unable to enjoy political freedom and execute their civil rights. We may observe advancements in the area of democratization in some African countries, such as Ghana and Liberia. Nevertheless, many African countries still have autocratic regimes: twenty-seven African countries have been listed as such in the 2010 Democracy Index prepared by the Economist Intelligence Unit.[2] Numerous African countries have been, or still are, going through long periods of civil and ethnic wars which lead to significant numbers of the residents being forced to flee from their indigenous lands.

The economic, humanitarian and political situation in Sub-Saharan Africa makes the countries of the region particularly vulnerable to any kind of economic disturbances. Additionally, the African continent has been severely impacted by climate change, facing droughts, medium temperatures' rise and deforestation. The continent is not properly equipped to tackle these challenges and adapt to the environmental transformations of the planet.

From the perspective of Sub-Saharan Africa, the history of developmental aid is mostly a recollection of drawbacks and failures, although few success stories can be told as well. Over the last thirty years, many countries have received abundant developmental assistance, yet they are still struggling to reach adequate levels of human development. This experience is equally true for those countries that demonstrated honest attempts to fulfill their conditional agreements, reform their administration and fight poverty, hunger and undernourishment. Given the scarce developmental resources, especially in the times of economic crisis, and the challenging international reform agenda, economists should work hard to try to understand the mechanisms behind spending, usage and effects of development assistance. Many researchers, journalists and politicians, both from Africa and the Western countries, call for a substantial reformulation and reform of the international development aid framework. Aid is often seen as being a disease rather than a cure for the African states.[3] Consequently, research on the effects of developmental aid is crucial in the process of designing an informed new development agenda. There is a wide range of areas where developmental aid is needed and shows a lot of promise. At the same time it is important to understand how additional investments could operate and which effects are probable or possible for each of the specific fields. Additional indirect effects, may they be positive or negative, should be taken into account.

This dissertation aims at providing insights into the aspects listed above by integrating development assistance and sector development programs into adequate economy-wide models for Sub-Saharan African states. The Computable General Equilibrium (CGE)

[2] See `http://graphics.eiu.com/PDF/Democracy_Index_2010_web.pdf` for details.
[3] E.g. Easterly [2006] and Moyo [2010].

methodology belongs to the standard toolkit of economic policy consulting. Even though it should not be considered to be the only possible instrument, it is capable of providing important and valuable insights in development policy as well as many other different policy areas. CGE models have a long tradition in development economics but their usage has been limited to a rather small community so far and they have not been used extensively in the field of aid-financed development programs during recent times.

This thesis comprises three different CGE models complemented by an econometric study. The models elaborate on various aspects of aid-financed development programs. The here-presented models are an important contribution to the respective modeling literature and add detail to their existing counterparts, especially in regards to the modeling of government behavior and the endogenous households' skill choice for their child members. The third model is a recursive-dynamic model which integrates educational production as well as the choice between child labor supply and schooling. It is also the first implementation of a recursive-dynamic model based on the International Food Policy Research Institute's (IFPRI) Social Accounting Matrix (SAM) structure as Mixed Complementarity Problem (MCP) using the MPSGE (Mathematical Programming System for General Equilibrium) modeling syntax.

The second chapter in this dissertation focuses on the direct spending effect resulting from development aid being paid to the government of an African state. It investigates whether so called *Dutch Disease* effects from aid are possible and probable, yet it goes beyond the Dutch Disease literature. The named phenomenon evolves mainly due to the distinctive government spending pattern favoring non-tradeable products. Increased aid leads to growth in these non-tradeable sectors, while a reduction of exports can be financed by the inflow of foreign exchange. The model and the analysis distinguish between different aid-spending strategies on the one hand and the possible second-round effect on productivity on the other. It thus combines the aspects of the Dutch Disease literature with a welfare analysis and possible compensation for Dutch Disease by increased productivity. The paper presents an application of the model to Zambia and subsequently incorporates the notion of enclave sectors in the economy (which is often the case in countries with large natural resources). The model presented in this paper has been applied in a specific evaluation project in Zambia by the Amsterdam Institute for International Development.[4]

The second chapter shows a necessity for productive investment. Of the following three chapters each concentrates on distinctive areas where development aid might be invested in a way that fosters productivity. The third and fifth chapter use CGE models as well, whereas chapter four consists of an econometric study.

Chapter three shows how the effects of infrastructure improvements can be explicitly

[4] See `http://www.aiid.org/page.php?id=40&project=10`.

captured in a CGE model setup. In contrast to many other studies, the paper depicts infrastructure as a transport cost-reducing element which improves market access by providing a low cost alternative to transportation services. The general modeling approach is demonstrated by means of a small illustrative model, tested econometrically, and then transferred onto a realistic model with full economic detail. The model is applied with a stylized Zambian SAM. The paper emphasizes the positive effect of an improved road network for market access, as well as its effects on home consumption and small-scale farming. Surprisingly, the model does not predict growth in the marketing of the agricultural products but an increased importance of the non-agricultural goods in the consumption bundle instead. Furthermore, it has been shown that the effects of infrastructure investment on income distribution strongly depend on the model assumptions. The effects are proportional to the increase in infrastructure; the model does not show decreasing returns.

Chapter four extends the econometric analysis of infrastructure in the third chapter and elaborates further on the econometric relationship between transport costs and the status of the road network. The paper combines input-output data, road network data, meteorological as well as geographical data in order to analyze the key factors determining transport costs across countries in a pooled estimation. The paper contributes to the transportation literature by developing and applying a new measure for transport costs. It uses the transport margin, i.e. the relative importance of transportation in overall sectoral production costs, as an internationally comparable and broadly available proxy for transport costs, whilst making a distinction between sector-specific and country-group-specific effects. Noteworthy differences between developed and developing countries are identified, which leads to the conclusion that evidence on the success of road network projects in industrialized countries cannot be easily transferred to the developing countries. Transport costs in industrialized states are strongly influenced by the road network density, the population density and urbanization, whereas these variables are of minor importance in the developing countries. For the latter, weather conditions and corruption are the most important determinants.

The last paper explores yet another important area of development policy: educational policy. It embeds the labor force effects from increased enrollment under different circumstances within a very detailed recursive-dynamic CGE model. The main advancement, as compared to other CGE studies in this field, lies in the explicit modeling of the educational process itself. The analysis includes the production of human capital in schools, the households' decision on time allocation for work and education respectively, as well as the skill choice between different skill levels. The model carefully considers the short term requirements in terms of skilled staff and physical schooling facilities, which require financing in order to increase enrollment, as well as the long term effects of the above on skilled labor provision. Moreover, the paper looks into the trade-off between current foregone earnings from child labor and future possible returns from higher education, doing so by including child labor into the model. This is a major improvement in comparison to other sequential dynamic educational models. The results of the model simulations show that welfare and production effects from better education arise only if both, schooling facilities and teachers, are available. Finally, the higher employment of high-skilled personnel in the public sector is detrimental to the other sectors. Households face an intertemporal trade-off as their short term income is indeed higher with lower enrollment and a positive effect from increased school attendance arises only in the medium term. I have developed and applied a very elaborate robustness testing procedure which is described in the paper in question.

The thesis concludes with the general lessons from the different applications hereby shown. It emphasizes the contributions that the models make in the area of CGE modeling for the developing countries of Sub-Saharan Africa.

2. Aid, Spending Strategies and Productivity Effects
A multi-sectoral CGE analysis for Zambia

Abstract

Numerous econometric studies fail to detect a significant and robust relationship between international aid and economic growth in the recipient countries. Dutch Disease effects might be responsible for this result. This paper examines the relation between aid and its effectiveness in a multi-sector multi-household Computable General Equilibrium-framework. Given that international transfers to African countries increasingly take the form of budgetary support, different spending strategies and their macroeconomic, sectoral and distributional effects are evaluated in a two-stage simulation making a distinction between immediate direct effects and possible long-run effects from increased productivity. The presence of sector-specific factors weakens Dutch Disease effects and shifts the burden of adjustment primarily to other exporting sectors. While the model simulates the effects of additional aid in Zambia it can be used as a blueprint for other African countries.

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Coauthor:	Prof. Dr. Volker Clausen

"THE WEST SPENT $2.3 TRILLION ON FOREIGN AID OVER THE LAST FIVE DECADES AND STILL HAD NOT MANAGED TO GET TWELVE-CENT MEDICINES TO CHILDREN TO PREVENT HALF OF ALL MALARIA DEATHS."
William Easterly, The White Man's Burden, 2006

2.1. Introduction

The question whether international aid is an effective instrument to foster sustainable economic development has been on the agenda for a long time [see Friedman, 1958; Bauer, 1972, and others]. This debate gained momentum with Boone [1994] who surprisingly found that aid had no impact on economic growth in developing countries. More recently, Easterly [2003] and Rajan & Subramanian [2008] provide empirical evidence in the same direction. In a comprehensive meta-study of the aid effectiveness literature Doucouliagos & Paldam [2008] conclude that international aid has no significant influence on growth in the recipient countries. Nonetheless, the discussion is far from being settled. A large number of studies find positive effects from aid or at least positive conditional effects [e.g. Burnside & Dollar, 2000; Hansen & Tarp, 2000]. Doucouliagos & Paldam [2010] however, do not find reliable support for a positive conditional relationship either.

In search for a possible explanation for the fact that many aid recipients, especially in Africa have not shown significant growth, several studies suggest that Dutch Disease effects weaken the impact of aid on growth [see e.g. Elbadawi, 1999; Rajan & Subramanian, 2005; Fielding, 2007; Doucouliagos & Paldam, 2009].[1] Aid inflows tend to be accompanied by an appreciation of the real exchange rate, a loss of international competitiveness and a corresponding contraction of the export sector. On the other hand recent studies by Adam & Bevan [2006] and Agenor *et al.* [2008] argue that these Dutch Disease effects may be overstated. They may disappear in a dynamic context if they are more than offset by large positive supply side effects. This holds as long as international aid is channeled into investment in the public capital stock and allows for productivity and output increases in the future. Moreover, Dutch Disease might depend on the production structure of the recipient country. [See Bandara, 1995]

The econometric finding of aid ineffectiveness, the potential role of Dutch Disease effects as well as different possible spending patterns of development aid call for a more disaggregate analysis. Against this background we explore the effects of additional aid flows in a Computable General Equilibrium model. The CGE framework allows for a detailed sectoral analysis. The simulations in this paper discriminate between different spending strategies (i.e. using aid for recurrent expenditure, capital expenditure, subsidies or transfer schemes) and consider different dimensions of aid effectiveness. Apart from that the setup clearly distinguishes between the negative side effects from a real-

[1] Other studies explain the observed ineffectiveness of development aid with absorption problems [see e.g. Heller, 2005; Torvik, 2001]. In general, the effectiveness of aid is likely to decrease with the degree of aid dependency [see e.g. Lensink & White, 1999, 2001; Dalgaard *et al.*, 2004].

location of resources at the sectoral level (i.e. Dutch Disease effects) and the potential positive effects from increased productivity.

CGE models have a long tradition in economics in general, and in development economics in particular. Nevertheless, the list of references with respect to the effects of international aid in these models is surprisingly short. Bandara [1995], Vos [1998], Adam & Bevan [2002, 2006] and Agenor *et al.* [2008] use CGE models to investigate the effects of large capital inflows to specific countries. These studies concentrate either on the demand or the supply side. They typically focus on only one specific use of aid most often public investment. All studies find evidence for aid-induced Dutch Disease effects but differ in their assessment of the strength of these effects.

Bandara [1995] shows in a static model for Sri Lanka that the effects of aid depend on the flexibility of the production structure in the receiving economy. He considers different degrees of factor mobility across sectors which explain different sectoral output and price responses. Vos [1998] uses a four sector dynamic general equilibrium model for Pakistan with an integrated capital market. He finds that the strength of Dutch Disease depends on the nature of the international transfer. It is more severe if aid takes the form of grants and is directly transferred to the government compared to the effects of foreign direct investment (FDI) or international loans. Adam & Bevan [2002, 2006] use a four sector two factor dynamic model for Uganda. They conclude that initial Dutch Disease effects could be overturned over time if all aid is productively invested and leads to productivity gains but only if these favor the nontradeable sector. In addition, Adam and Bevan find negative distributional effects. Agenor *et al.* [2008] use a dynamic one-sector-one-household approach with a very elaborate government sector. Most aspects of Dutch Disease are excluded from their model design as the highly aggregated setup does not account for sectoral reallocation. Nevertheless, they conclude that negative effects from aid could be avoided if the supply response is sufficiently large and the absorptive capacity of the recipient country is sufficiently high. However, the underlying macro model with only one representative household and one sector is clearly restrictive.

This paper provides a comprehensive account of the issues in a detailed CGE model based on a real world data set. The simulation results are generated by an 11-sector-5-household static CGE for Zambia. Zambia is one of the 50 least developed countries and will probably receive substantially more aid in the near future [see OECD & AfDB, 2007]. The possible effects of these additional aid flows are analysed in a sequence of simulations. We add to the aforementioned literature by explicitly modeling different possible spending strategies available to the Zambian government.

In order to clearly discriminate between the immediate effects from spending and the long-run productivity effects from public capital formation we adopt a two-stage approach. The first stage only covers demand effects, the second stage adds productivity effects. It is shown that the specific structure of the Zambian economy induces large sectoral shifts in production and makes the Zambian export sector very vulnerable if factors are assumed to be mobile across sectors. Countries with similar economic profiles are likely to experience comparably negative Dutch Disease effects from international aid. Dutch Disease effects might be lower if the production factors in exporting sectors are immobile. Furthermore, depending on the spending scenario, international aid may have adverse effects on income distribution and make poor households worse off, not only in relative but also in absolute terms.

The remainder of this paper is structured as follows: The next section defines the term *aid* and outlines different dimensions of *aid effectiveness*. Section 3 describes the model. Section 4 gives an overview of the data and describes the parametrisation. Section 5 motivates and describes the different spending scenarios. Section 6 presents the simulation results. Section 7 concludes.

2.2. Aid and Aid Effectiveness

Most macroeconomic studies do not distinguish between different forms of aid as the underlying data on its specific uses are typically unavailable. The data set in our CGE model defines international aid as the amount of foreign grants reported in the government budget. Hence the CGE model only covers official development assistance (ODA) being paid to the government and reported in the budget.[2] This covers only a part, but still the majority of aid given to Zambia (about 70-80% of aid in recent years).[3]

Aid can be used for public consumption, public investment or for payments to the private sector (social transfers and investment subsidies). Most previous CGE studies and also most theoretical analyses on aid effectiveness assume that aid is used for productive capital investment and increases public capital accumulation. However, a growing proportion of aid is provided as direct budgetary support [see OECD & AfDB, 2006, p. 525] and does not necessarily increase public capital accumulation. Fagernäs & Roberts [2004] show that increased aid has a positive influence on recurrent expenditure and a negative influence on tax disciplice in the receiving economy. For this reason this paper compares five different spending scenarios. The benchmark case refers to the actual composition of the government budget in Zambia in 2001 and assumes that aid is spent correspondingly. The respective shares of the three possible uses of aid are then modified in order to focus on the different spending strategies.

Our CGE model is a static model and captures mainly the steady state impact of aid,

[2] The aid variable does not cover private aid, humanitarian aid, technical assistance or tied aid and does not explicitly account for military aid and short-term credits even though parts of the base year aid might have belonged to these categories.

[3] This is not a major concern as the volume of base-year aid is only a scaling factor. In order to account for this measurement problem, different increases in aid have been simulated in robustness checks.

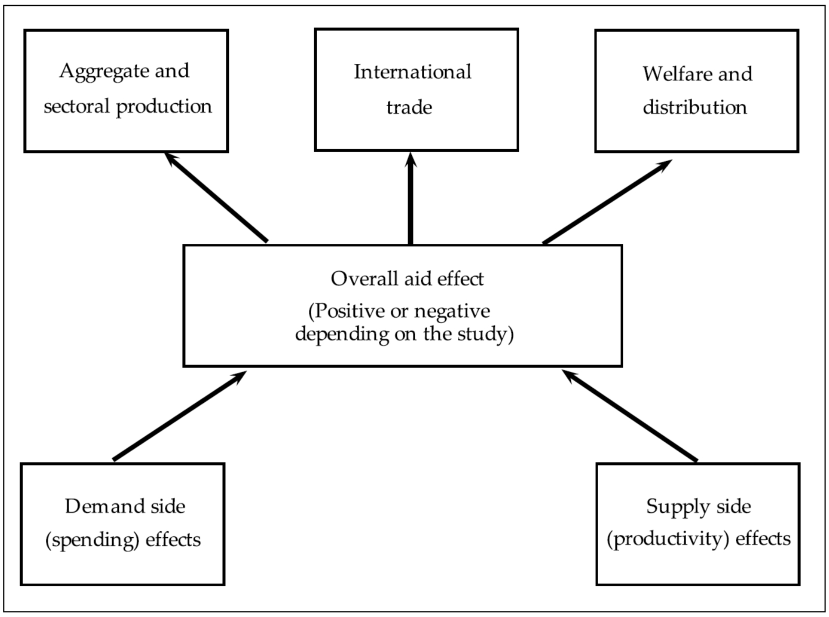


Figure 2.1.: Disentangling the different effects from increased aid

leaving aside the adjustment dynamics.[4] It is based on a real data set from the base year (2001).

The effectiveness of aid is measured in most macroeconomic studies only with respect to economic growth [see Doucouliagos & Paldam, 2008]. This paper broadens the perspective and evaluates three different types of indicators. The simulations illustrate the effects of increased aid on sectoral and aggregate production, the trade balance as well as on welfare and income distribution. Following this broader assessment aid will be considered effective as long as it promotes growth and international trade and leads to (over-proportional) increases of the income of poor households, i.e. in the case of Zambia the income of small farmers and self-employed. It will be shown that there exists a trade-off between these objectives for Zambia.

Figure 2.1 provides a brief overview of the different types of aid effects. A first distinction can be drawn between demand and supply side effects. Demand side effects are mainly direct effects from the spending of aid in the recipient country. Governments tend to use aid mainly for the purchase of non-tradeable goods. The first and most direct effect from aid will be increased demand for non-tradeables. This increase in domestic demand leads to rising domestic prices of non-tradeables relative to tradeables' prices that are

[4]CGE models with a focus on development issues are often specified as static models partly because of generally low savings and investment rates in those countries. For this reason endogenous private capital accumulation plays a smaller role and the simulation results from a static model provide to a first approximation a broadly reliable guide to the ultimate long-term effects of development aid. Nevertheless, the paper needs to introduce some aspects of (quasi)-dynamics in order to evaluate the impact of the different spending scenarios on a comparable basis. The impact of spending may be short-term (such as on public consumption) or of a longer-term nature via the stock of public capital which generates lasting productivity effects. Jensen [2009] provides a disaggregated perspective on the investment-productivity link for one specific form of public capital, roads,

fixed on world markets, i.e. to an appreciation of the real exchange rate. The receiving government can use aid either for recurrent or for capital expenditure, recurrent spending normally comprises only non-tradeable goods (public services). The share of imported goods increases with the importance of capital investment in the aid-financed expenditure. Alternatively, the government could transfer inflowing aid to the private sector where it allows for higher consumption or higher investment. The resulting increase in imports again depends on the type of spending as consumption is dominated by domestic goods whereas investment requires imports. In general, the size of the demand-driven Dutch Disease effects might be limited if factors are not fully mobile between tradeable and non-tradeable sectors.

The supply side effects mostly arise from productive public investment and increased public capital accumulation. The government may use the additional funds for public capital accumulation as Adam & Bevan [2006] assume in their model of aid effectiveness. Aid may be invested in health and education programs which increase labor productivity. Or it may be used for infrastructure investment which increases total factor productivity [see Agenor *et al.*, 2008; Jensen, 2009]. Aid could also be transferred to private investors and hence add directly to private capital accumulation. These productivity effects have the potential to increase domestic supply and to reduce Dutch Disease effects. In general, the spending of additional aid incurs sectoral shifts in production. The direction of these sectoral reallocations depends on differences in factor intensity, the share of imported intermediates and productivity effects from aid [see Heller, 2005].

Distributional effects from aid result from changes in the relative goods and factor prices. Undesirable distributional effects might occur as increased demand and prices might lead to a rise in the return to high-skilled labor which is mainly an income source of wealthy households. The rise in domestic prices could be to the detriment of the poor. The overall distributional consequences can only be captured in an CGE model which keeps track of all changes in goods and factor prices. Furthermore household specific consumption patterns, also with respect to subsistence agriculture, can fully be addressed.

2.3. The Computable General Equilibrium Model

The model draws partly on the Tanzania model and the MPSGE version of the IFPRI model by Thomas Rutherford [see Rutherford, 2003] but it has been completed by a number of new features and aid-specific elements. It is written in GAMS/MPSGE vector syntax [see Rutherford, 1999]. Compared to standard developing country CGEs the model has a very detailed government account and allows for different uses of aid. Moreover, it includes a productivity parameter which depends endogenously on the amount of aid spent on public investment. In the following we describe the basic features of the Zambia model and its parametrisation.

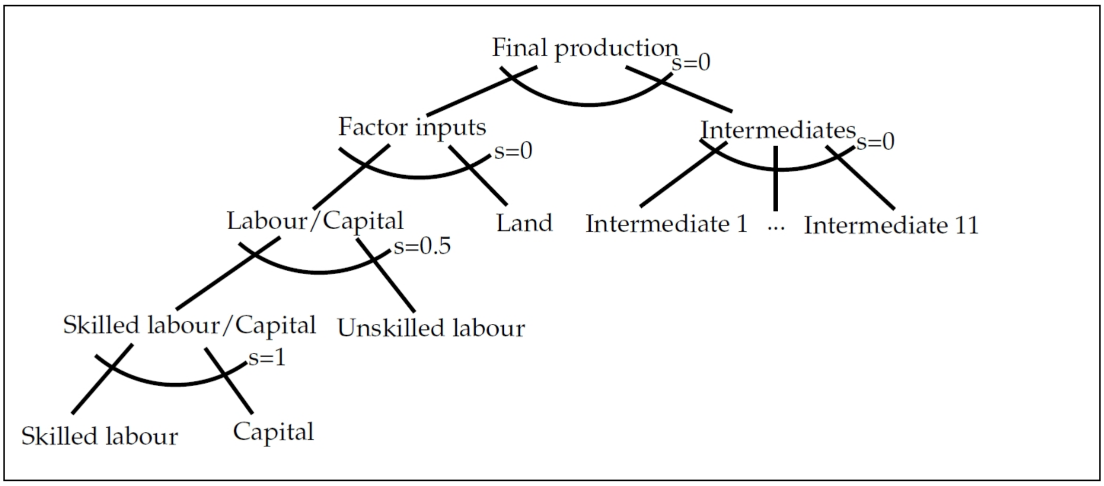


Figure 2.2.: Nesting structure of domestic production xd(i)

2.3.1. Production

Production in Zambia is disaggregated into eleven sectors of production, three of which are agricultural, five industrial and three are services. In each sector output is produced from a specific combination of intermediate inputs, capital, land and two different types of labor.

$$xd_i = xd_i \left(\sum_j \overset{+}{int}_{j,i}, \overset{+}{fd}_i(skl, unskl, cap, land) \right) \tag{2.1}$$

where $int_{j,i}$ is the intermediate demand for good j in sector i and fd_i is the demand for factors (skilled labor, unskilled labor, capital and land) in sector i. In the baseline specification, labor and capital are assumed to be perfectly mobile across sectors. The production process is modeled using a nested production function as shown in figure 2.2.

Skilled labor and capital are imperfect substitutes in a Cobb-Douglas production function with a corresponding elasticity of substitution (s=1). We assume the substitutability between unskilled labor and skilled labor/capital to be more limited (s=0.5). The combination with land takes the form of a Leontief production function (s=0). Substitution between different intermediates or between intermediates and factors of production is again ruled out by the assumption of Leontief functions (s=0).[5]

Domestic production is either sold on (domestic or foreign) markets (x_i) or directly consumed at home ($hc_{i,h}$):

$$xd_i = x_i + \sum_h hc_{i,h} \tag{2.2}$$

Zambia is modeled as an Armington economy. Domestic goods are imperfect sub-

[5]Note that other nesting structures have been examined in robustness checks and do not have an influence on the qualitative simulation results.

stitutes for foreign goods. Domestically produced goods are combined with imported supply in a Constant Elasticity of Substitution (CES) function to form the Armington aggregate which is sold on domestic markets. Domestically produced goods may also be exported, but production of exports differs from production for local markets. This is implemented using a Constant Elasticity of Transformation (CET) function.

$$a_i = a_i\left(\overset{+}{x_i^{dom}}, \overset{+}{im_i}\right) \tag{2.3}$$

$$x_i = x_i^{dom}(\overset{+}{pd_i}) + ex_i(\overset{+}{pw_i}) \tag{2.4}$$

where x_i^{dom} is the part of domestic production which is sold domestically and im_i and ex_i are imports and exports in sector i respectively. The structure of the supply side is shown in figure 2.3.

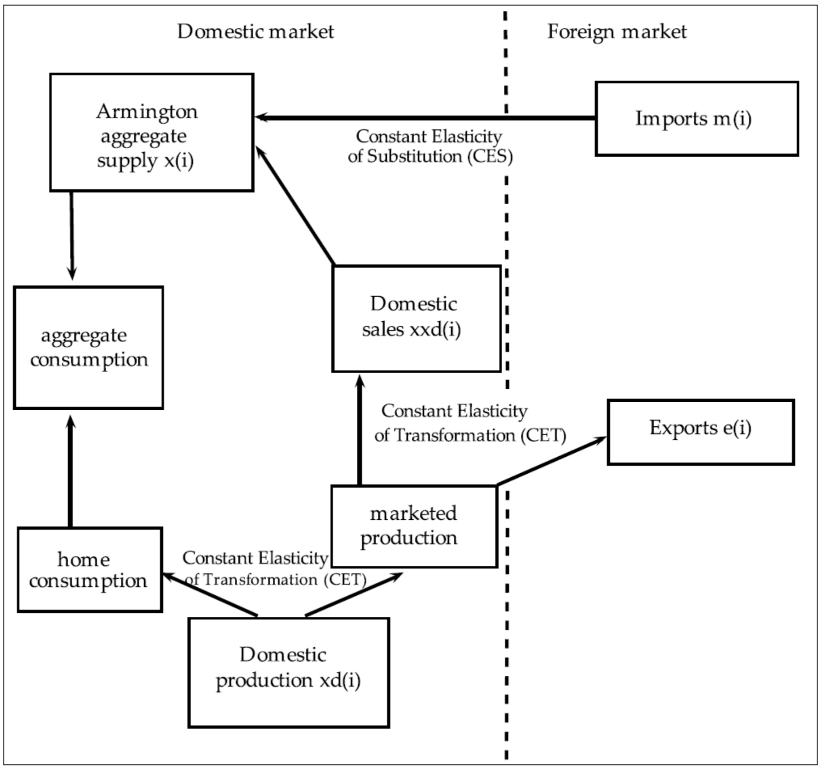


Figure 2.3.: Production, marketing and consumption the economy

2.3.2. Demand

Domestic demand consists of household demand, government consumption, investment and intermediate demand. Intermediate demand is linearly linked to the quantity of output. Household demand and government spending and investment are described below.

The model has five household types which differ in their main source of income, their level of income, their income tax rate[6] and in their marginal propensity to save. Households generate income from labor, capital, land and entrepreneurial activities. Apart from these income sources households receive transfers from other households, from the government and from abroad. Income is used for tax payments, consumption, transfer payments and savings[7]:

$$y_h = y_h\left(\sum_f \overset{+}{fs}_{f,h} \cdot pf_f, \overset{+}{ent}_h \cdot pe, \sum_g \overset{+}{trans}_{g,h}, \overset{+}{govtrans}_h, \overset{+}{ftrans}_h\right) \tag{2.5}$$

$$c_h = c_h\left(\overset{+}{y}_h, \overset{-}{s}_h, \sum_g \overset{-}{trans}_{h,g}, \overset{-}{td}_h, \sum_i \overset{+}{hc}_{i,h}, \overset{-}{pc}_h\right) \tag{2.6}$$

Where y_h is the income of household h, $fs_{f,h}$ is the factor supply of factor f by household h, with pf being the respective wages. Ent_h is incomce from entrepreneurial activity, with pe being the respective wage. $trans$ is the matrix of interhousehold transfers and $govtrans$ and $ftrans$ are the vectors of government transfers and foreign transfers respectively. c_h is the consumption of household h, s_h are savings of household h and td are direct taxes on household income, pc_h is the price of the household-specific consumption bundle. Details on the different household types are given in table 2.4 in the appendix (A).

The government generates income (y_{gov}) from taxes, public capital and international aid (aid).

$$y_{gov} = y_{gov}\left(\sum_h td_h, te, \sum_i vat_i, \sum_i tar_i, \sum_i ti_i, ent_{gov}, aid\right) \tag{2.7}$$

Where td and te are direct taxes on household and enterprise income respectively, vat_i are value added taxes, tar_i is income from tariffs, ti_i are indirect production taxes in sector i, ent_{gov} is income from public enterprises.

$$c_{gov} \cdot pg = y_{gov} - pubinv - subs - interest - \sum_h govtrans_h \tag{2.8}$$

It spends its revenue on public consumption ($c_{gov} \cdot pg$), transfers to households, subsidies ($subs$), interest payments ($interest$) to the rest of the world and public investment ($pubinv$). Transfers, subsidies and interest payments are exogenously fixed. The only good the government consumes are public services. Public investment consists mainly of construction and to a smaller extent of capital goods. In contrast to most other CGE applications the government does not only act as a mere redistributor but has in addition

[6] In contrast to the Tanzania model, income tax revenues rise in proportion with the income level and differ across households. This implies that the government indirectly benefits from increased transfers and rising wages.

[7] A substantial part of household consumption is directly satisfied from their own production of food, the so-called home consumption. It is important to include this into the model as this production is not marketed but must be accounted for in the assessment of the strength of welfare effects.

a distinct consumption and investment function.[8] This allows for the identification of the specific effects from government spending compared to private spending. Only this disaggregated view on the government allows for a complete picture of Dutch Disease effects from aid. These might in fact differ from traditional Dutch Disease from resource booms or other windfall gains. By means of the government-specific consumption and investment functions it is possible to clearly distinguish the effects of different forms of increased government spending.

Savings are generated by households, enterprises and the rest of the world. Savings are used for private capital investment. Total investment is always chosen to equal total savings. Investment demand for the two investment goods is determined in a Leontief fashion.

2.3.3. Modeling of aid

Aid is specified as grants to the government, which may use it for its own spending purposes or transfer it to the private sector. Aid is taken as a financial transfer from the rest of the world which allows the country to finance additional net imports. This assumption implies an extension of the balance of payments from additional international aid [see Bandara, 1995, p.316-317]. This net trade balance will be held fixed across all following scenarios in order to allow for a valid comparison across policy scenarios.

The scaling up of aid is implemented using a multiplier with the initial level of aid in the government's income equation. The respective use of aid is modeled by the choice of the shares of the different components in the budget. The government may use the additional aid either for public consumption, public investment, transfers, subsidies or for a combination of these elements.

2.3.4. Sector-specific factors

Dutch Disease effects, i.e. an expansion of the production of non-tradeables at the expense of tradeable sectors, are driven by migration of factors from tradeable to non-tradeable sectors. The first face high competition on world markets and thus have no possibility to increase prices and wages. Hence, Dutch Disease effects would be limited if either factors are not (completely) mobile across sectors or if factor supply would not be fixed, in our case if the effective factor supply would increase with public investment financed by aid. We model both situations, separately, in order to show to which extent Dutch Disease might be limited.

Most of the labor force in our dataset is unskilled. These workers have only finished primary school or even not finished primary school. Thus we assume that these workers do not accumulate sector-specific human capital and labor should not be considered

[8] To our knowledge a combination of government specific consumption and investment in one model has so far not been implemented in aid-focused developing country CGEs.

as potentially sector specific. The exporting sectors are mining, manufactured mining products and agricultural exports. These sectors suffer from potential loss of their production factors. As most exports depend on mining production, we focus our simulations concerning sector specific factors on the mining sector. Given that this sector is highly capital-intensive and capital in mining is very specialised, we assume in some of our simulations that capital in mining is sector-specific and the supply is fixed.

2.3.5. Modeling of productivity effects

The productivity effects from increased public investment are captured as in Markusen [2002] by introducing a multiplier on factor endowments. An increase in total factor productivity leads hence to an increase in the effective supply of factors. It is assumed that the increase in total factor productivity is uniform across all factors and also across sectors.[9] In the benchmark scenario the respective parameter is set to unity, such that effective factor supply equals the actual factor supply in the base year. In the counterfactual, public capital formation increases the effective supply of factors of production. The respective elasticity of total factor productivity with respect to public investment is taken from the literature. Our parameter choice is based on the numerous estimations of Hulten [1996]. He estimates this elasticity to be between 0.12 and 0.25 depending on the specification of the model. These two values have been used.[10]

2.4. Data and Parameterisation

2.4.1. Data

Zambia is very aid dependent, almost 30% of the government budget is financed by external assistance [see OECD & AfDB, 2007, p.552]. Public capital formation relies strongly on external support: up to 70-80% is financed by external sources. In 2001, the base year of our analysis, total ODA (grants and loans) disbursed to Zambia from the OECD countries amounted to roughly 11% of the Zambian GDP [see SourceOECD, 2007]. The Zambian government draws the financing of its Poverty Reduction Strategy (PRS) largely upon increased aid flows even though these are conditional on the implementation of institutional and accounting reforms [see OECD & AfDB, 2007, p.552]. The Zambian aid receipts have been used for public capital accumulation especially in infrastructure but also for the health and education sectors as well as for administrative reforms. For Zambia the assumption by Adam & Bevan [2006] that most or all aid is used for public capital formation is not appropriate. Even though grants and total ODA

[9] Jensen [2009] models the productivity effects from public investment more specifically by modeling the reduction in transport costs due to road investments, unfortunately this captures only a part (appr. 20% in the Zambian case) of total public investment. We chose this rather general way of modeling the productivity gains from public investment as our focus lies on the comparison of different uses as opposed to the detailed investigation of one specific use only.

[10] An elasticity of 0.12 means that doubling public investment would increase the effective factor supply by 12%. Other values have been tested in robustness checks. Note that Adam & Bevan [2006] use a somewhat higher value of 0.5.

(including loans) have recently increased relative to GDP, public capital accumulation has fallen relative to GDP. Increased aid has not resulted in increased public investment [see OECD & AfDB, 2008, p.619].

In 2006, the Zambian domestic production was structured as follows: 20% were produced in the agricultural sector, 32% in the industrial sector and 49% in the services sector.[11] Zambian exports rely mainly on three sectors: Mining, which contributed 4% to the 2006 GDP and roughly 60% to total exports, traditional agricultural products (coffee, tea, tobacco, sugar, cotton) and manufactured copper products (rods and wires) which constitute another 20% of Zambian exports. The main Zambian imports are capital goods, manufactured goods and processed food.[12] The main consumption goods are agricultural products, mostly food but also manufactured goods and private and public services.

Most parameters, such as expenditure shares for households, the government and the investment function, as well as parameters for production technologies and preferences can be computed directly from the data.[13] The Social Accounting Matrix (SAM) has been suitably aggregated for the purpose of this analysis. This data has been complemented with data from the national accounts for foreign grant inflows and interest payments.[14]

2.4.2. Parameterisation

For Zambia, like for most developing countries, estimated elasticities of substitution and transformation are unavailable. For convenience, Cobb-Douglas and Leontief functions are mainly used for the production functions. This conforms with most other CGE applications and also with empirical results confirming that substitutability between factors is very limited in developing countries [see Duffy & Papageorgiou, 2000; Agenor *et al.*, 2008]. The Armington function elasticities have been chosen as in other developing country applications between 0.4 for capital goods and manufacturing and 1.5 for agricultural products [see Dervis *et al.*, 1982].[15] For exports it is assumed that in agricultural sectors the shift from domestic supply to export supply is easier than in the other sectors, whereas in manufacturing and capital goods production it is rather costly to switch to a different destination market. Elasticities of transformation are specified between -0.5 in manufacturing and capital goods and -1.1 mining and basic food processing. World market prices are exogenous and act as a numeraire in the model.

[11] Data for 2006 taken from Kufa *et al.* [2008, p. 3]. The Zambian production and consumption structure in the base year (2001) is given in table 2.2 in the appendix.
[12] See table 2.3 in the appendix for more information on the trade structure.
[13] The basic SAM has been provided by the International Food Policy Research Institute. It is described in detail by Thurlow *et al.* [2004].
[14] National accounts data has been taken from the statistical appendices of different IMF-Country reports on Zambia, mainly Akatu *et al.* [2006] and IMF [2005], and the Zambian Poverty Reduction strategy paper [see Government of the Republic of Zambia, 2002] as well as the Public Expenditure Reviews and the OECD African Economic Outlook [see OECD & AfDB, 2007; OECD & AfDB, 2008].
[15] Alternative specifications have been tested in robustness checks.

2.5. Spending scenarios

The Zambia model is used to simulate alternative spending scenarios for the additional aid inflows. Results will be presented for a 45% increase in grants which corresponds to about 2.5% of the Zambian GDP and lies in between the average annual increase in the recent past and the expected increase given in the Fifth National Development plan.[16]

Four core strategies are distinguished for the use of additional aid. It could be spent on public investment, enhancing the infrastructure, enlarging the public capital in health and education and aiming at a broad increase in total factor productivity. It could be used for public consumption i.e. public services especially on current expenditures for health and education to enhance the social and health situation and the living standard especially of the poor. Or it could be transferred to the private sector where it may be spent either on private consumption or on private investment. All other possible spending strategies (i.e. forms of aid) represent hybrid forms of the above.

Most previous CGE applications on increased aid assume that the additional resources are entirely invested or even that if aid enters the country in the form of imported capital goods. For the sake of comparison an investment-only scenario is simulated here, too. A growing proportion of aid is allocated in form of budgetary support [see OECD & AfDB, 2007], which means that a part of it will also be spent on recurrent expenditure. In addition, it can be observed in Zambia like in many other countries, that aid simply substitutes for the public investment budget of the government and thus indirectly raises the recurrent expenditure as the tax receipts are now redirected towards recurrent purposes [see Fagernäs & Roberts, 2004]. In view of the growing importance of budgetary support and the possible shift in the use of tax receipts, it is very likely that aid will also increase recurrent expenditure. In consequence a hybrid scenario with a proportion of aid used for public consumption and for transfers to private households is simulated here as well. A pure public consumption scenario completes the spectrum of possible spending scenarios. The results of 14 scenarios are presented in table 2.1.

We first simulate the direct effects from increased public spending in particular sectors. We call these the demand-driven effects. In a second step we add features to the model that potentially limit Dutch Disease effects: Limited intersectoral factor mobility and increased factor productivity from public investment financed by aid.

2.6. Simulation results

This section presents the key simulation results starting with the aggregate and sectoral effects on production followed by the trade balance effects and closing with the welfare

[16]See Zambian Ministry of Finance and National Planning [2005, p.242-245]. Increases in aid between 15 and 100% have been tested in robustness tests. The qualitative results remain robust, the extent of the effects is almost linearly linked to the amount of aid provided.

Table 2.1.: Spending scenarios

Stage 1 - **Direct spending effects**

Index	Scenario	Description
NAIV	**Proportional increase**	Reference scenario. Government spending pattern from the benchmark SAM is retained. Budgetary support. Public consumption (58%), public investment (24%), transfers (18%).
PUBINV	**Public investment**	Additional aid is entirely invested by the government. Programme/Project aid. Infrastructure, health and sanitation, education.
PUBCONS	**Public consumption**	Additional aid entirely used for government consumption. Aid finances current expenditure on health, education and public administration.
PRIVINV	**Private investment**	Additional aid fully transformed into private investment (e.g. micro-credits).
TRANS	**Transfer scenario**	Additional aid fully transferred to private households and used for consumption and savings.

Stage 1 - **Scenarios with sector-specific capital in mining**

NAIV_CAP	**Proportional increase, mining-specific capital**	Strategy corresponds to scenario NAIV but capital in the mining sector is sector specific.
PUBINV_CAP	**Public investment, mining-specific capital**	Strategy corresponds to scenario PUBINV but capital in the mining sector is sector specific.
PUBCONS_CAP	**Public consumption, mining-specific capital**	Strategy corresponds to scenario PUBCONS but capital in the mining sector is sector specific.
PRIVINV_CAP	**Private investment, mining-specific capital**	Strategy corresponds to scenario PRIVINV but capital in the mining sector is sector specific.
TRANS_CAP	**Transfer scenario, mining-specific capital**	Strategy corresponds to scenario TRANS but capital in the mining sector is sector specific.

Stage 2 - **Scenarios with productivity effects**

NAIV_LOW	**Proportional increase, low productivity**	Strategy corresponds to scenario NAIV. 1% increase in public investment $\Rightarrow$ 0.12% productivity effect.
NAIV_HIGH	**Proportional increase, high productivity**	Strategy corresponds to scenario NAIV. 1% increase in public investment $\Rightarrow$ 0.25% productivity effect.
PUBINV_LOW	**Public investment, low productivity**	Strategy corresponds to scenario PUBINV. 1% increase in public investment $\Rightarrow$ 0.12% productivity effect.
PUBINV_HIGH	**Public investment, high productivity**	Strategy corresponds to scenario PUBINV. 1% increase in public investment $\Rightarrow$ 0.25% productivity effect.

and distributional effects. First the demand driven effects (stage 1) are presented, in the second part of this section, a productivity response to public investment is included (stage 2). The sensitivity analysis reveals to which extent the assumed share of investment spending in the use of aid as well as the assumed strength of the productivity effects influence the results.

2.6.1. Stage 1 - Demand driven (spending) effects

Due to the exogenous fixed supply of all factors of production, an increase of spending from aid is bound to leave the economy without noteworthy immediate aggregate output effects. The simulations confirm that aid has no significant impact on aggregate real GDP as long as it is used for non-investment purposes or, if it is invested, lacks to have any effects on productivity.[17] At a disaggregated level only few sectors strongly benefit from the additional aid flows whereas production in most other sectors remains largely unchanged or diminishes slightly. The expansion of the *construction* sector (from public investment) and the *public services* sector (from public consumption) comes at the expense of the contraction of the two main exporting sectors *mining* and *agricultural exports*. Figure 2.4 shows the percentage changes in sectoral production. The mining sector which is the most important export sector and contributes about 60% to Zambian exports, suffers in almost all scenarios from the most severe decline in production. In most cases the exporting sector *agricultural exports* suffers, too. The transfer scenario hurts agricultural exports most strongly. The rise in transfers goes primarily to the poor who spend their income almost exclusively on food. The resulting price increase for food encourages domestic food producers to reallocate their production from exports toward domestic supply. The contraction of output in mining and agriculture is accompanied by a fall in their corresponding exports.[18]

The sectoral production and trade effects result from a reallocation of productive resources from the exporting sectors to the non-tradeable sectors *construction* and *public services*. The mining sector, in particular, suffers from a fall in its used capital and in its employed work force, especially of skilled labor. Mining production is very capital intensive and employs a high share of the Zambian capital stock. The sector loses up to 10% of its capital stock and up to 15% of its skilled labor force. Given the importance of the mining sector for the Zambian economy this result should be taken very seriously. The factor reallocation is illustrated for the case of skilled labor in figure 2.5.

If only a small proportion of aid is used in a way that increases factor productivity, like e.g. budgetary support, most sectors are hit by negative effects on their sectoral

[17]The results are therefore not shown here. In the robustness checks we alternatively introduce unemployed unskilled labor. This does not affect the qualitative results as unskilled labor is not a perfect substitute for skilled labor or capital. The consideration of initial unemployment has some effects on income distribution but it has been left out of the basic models for the sake of simplicity and due to a lack of reliable data on unemployment levels.

[18]Sectoral trade effects are not shown here for brevity.

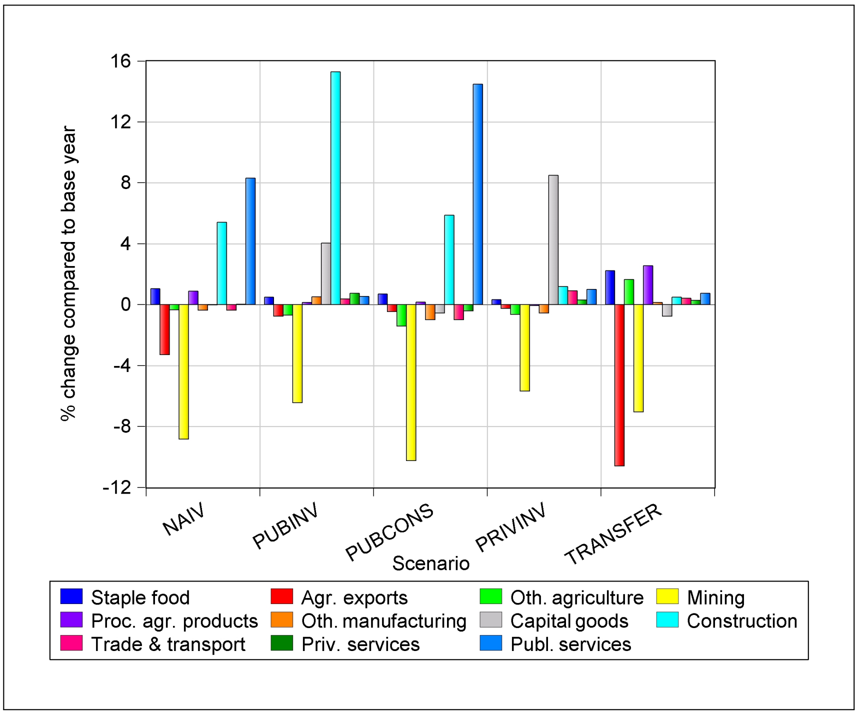


Figure 2.4.: Effect of aid on sectoral production

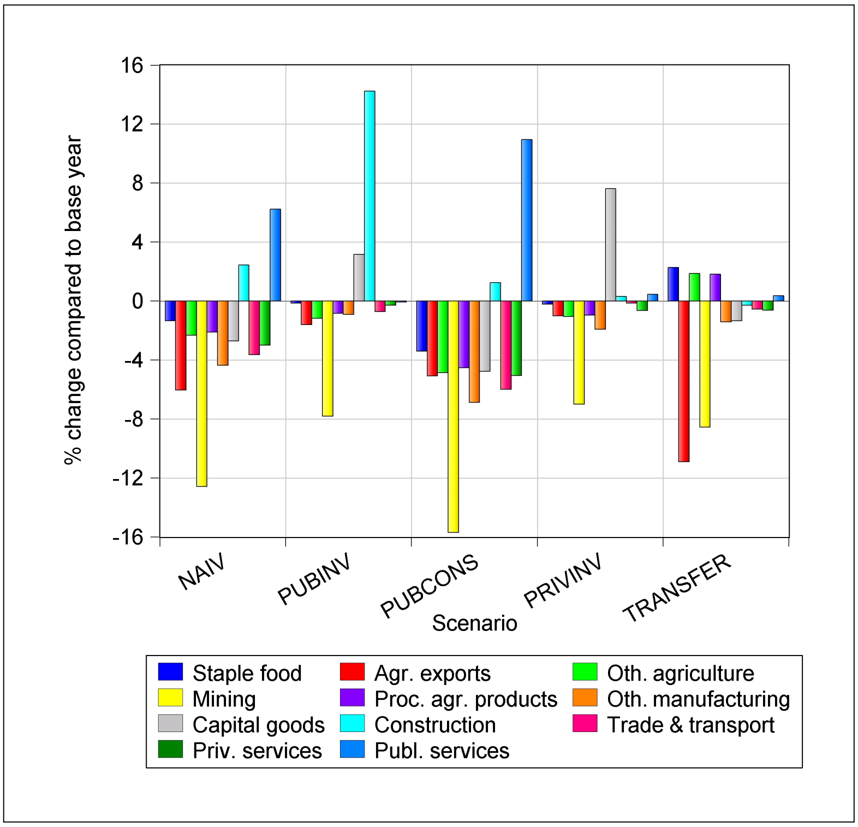


Figure 2.5.: Effect of aid on the sectoral use of skilled labor

production, exports and employment. In these cases only those sectors benefit which are directly addressed by government spending, namely *construction* and *public services*. The additional private income does not translate into noteworthy effects on the other sectors and exporting sectors are clearly worse off. Overall, the sectoral simulation results provide a more complete picture of the effects from increased public spending financed by aid compared to the aggregate results alone. The shift of production and factor use from exporting to domestic sectors clearly documents considerable Dutch Disease effects from international aid.

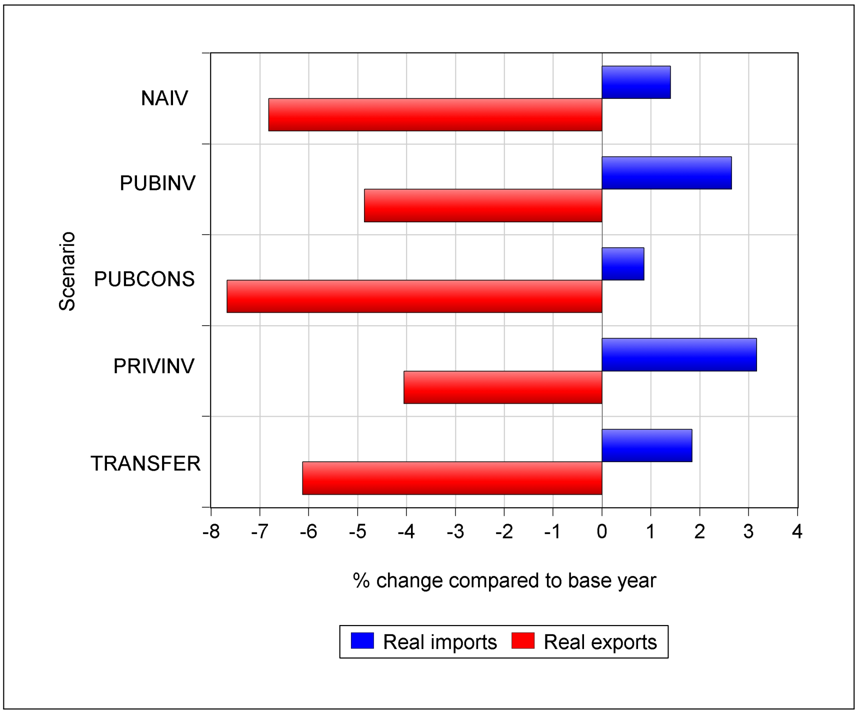


Figure 2.6.: Effect of aid on the trade balance

As regards to the trade balance effects, the increase in international aid allows for an increased current account deficit. The increased deficit could either make room for increased imports, like e.g. Heller [2005] proposes, or for reduced exports. In all scenarios a mixture of both arises but some scenarios are biased in favor of increased imports whereas especially the consumption scenarios (NAIV, PUBCONS and TRANS) lead to decreasing exports.[19] Figure 2.6 shows that the consumption scenarios in particular are followed by declining exports whereas in the full investment scenarios (PUBINV and PRIVINV) imports rise substantially. In comparison with private investment public investment falls to a larger extent on construction and less on imported capital goods. The Dutch Disease effect on domestic exports is smallest in the case of private investment

[19]Torvik [2001] and Adam & O'Connell [2004] argue that Dutch Disease and the downward pressure on the export sector could be aggravated through negative learning by doing effects. A decline in output in the exporting sector causes a fall in productivity in these sectors and a further loss of international competitiveness. These additional, mutually reinforcing effects of Dutch Disease remain outside the scope of the present analysis.

(-4%). In contrast, an increase in public consumption induces the strongest Dutch Disease effects as the increased public demand falls almost exclusively on public services as a non-tradeable domestic good.

If aid leads to an increased demand for non-tradeable goods it will raise their relative price as production capacities are limited. This price increase or real appreciation attracts factors of production to the non-tradeable sectors and leads to a reduction in exports. The real appreciation is weaker in the private investment scenario but it is of noteworthy size in all scenarios.[20] It follows that even if aid is mainly invested some Dutch Disease effects are likely. This results from the specific structure of exports in Zambia which is highly concentrated and specialised. There exist only two important export sectors which produce about 90% of Zambian exports. These sectors sell their production almost entirely on world markets.

In order to assess aid effectiveness the choice of the adequate welfare measure is crucial. Most CGE applications use as welfare measures either the Hicks equivalent change in household income or real GDP.[21] The Hicks equivalent change in welfare is the percentage change in real private consumption. Note, however, that the presence of government spending requires additional measures. The Hicks equivalent does not include public spending if it does not enter the households' consumption bundle. Correspondingly, an increase in public consumption does not have a direct impact on private welfare measured by the Hicks equivalent. For the sake of comparison, we also provide a broader measure including public spending and present the percentage change in aggregate real private and public spending. While the Hicks equivalent as the conventional welfare measure is more accurate as it is defined in equivalent terms, the broader measure including real public consumption assumes that public spending is exactly as valuable as private spending and in addition is not defined as equivalent change. This measure alone is likely to overstate the welfare effect but it allows for a comparison of the different scenarios.

An increase in aid raises the Hicksian equivalent even if it is not or unproductively invested. The strength of the welfare effect depends on the use of aid. The effect is higher in public investment and transfer scenarios. Figure 2.7 summarizes the welfare effects in the different scenarios. Note that if aid is completely spent on public consumption it has a *negative* effect on the Hicks equivalent change in income. This is due to the fact that the Hicks equivalent only measures welfare of private households. In contrast the broader welfare (TOTEXP) measure including real public spending on consumption or investment rises substantially in almost all scenarios except for spending on private investment.

Even though only 24% of aid is invested in the NAIV scenario, the effect on the Hick-

[20]Results for the real exchange rate are shown in 2.5 in the appendix.
[21]See for example Rutherford & Tarr [2008].

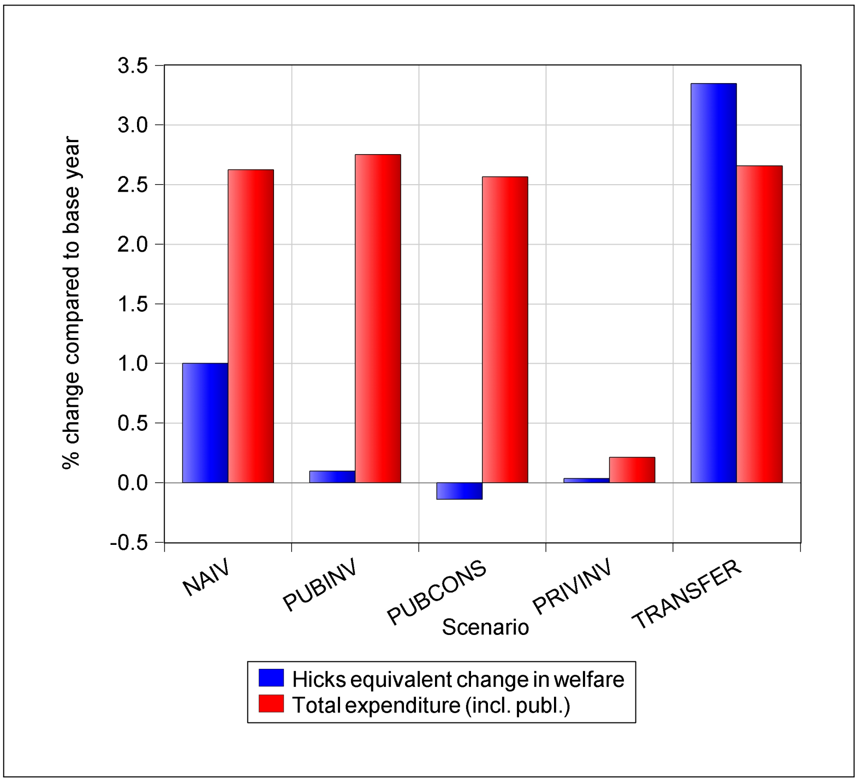


Figure 2.7.: Effect of aid using alternative welfare measures

sian equivalent is relatively strong. This follows from the fact that 18% of aid are directly transferred to private households and thus directly add to private welfare. The same is true for the TRANS scenario in which all aid directly enters private spending.

Adam & Bevan [2006] point out in their simulations of disaggregated welfare effects that additional aid always leaves the rural households relatively worse off. Figure 2.8 shows the changes in the Hicksian equivalent for different household types across scenarios. The distributional effects clearly depend on the assumed spending pattern. In the consumption-focused scenarios (NAIV, PUBCONS and TRANS) income effects favor the rural households (57.6% of the population) and run against self-employed households (21.5% of the population) and employers (1% of the population). In contrast, in the investment-focused scenarios (PUBINV and PRIVINV) the distributional effects are more balanced. Nonetheless, across all scenarios the self-employed benefit only underproportionally from aid-induced welfare gains or are even absolutely worse off in real terms. The same is true for employers but this is only a small group.

Small and medium farms represent the largest and poorest group of the population. They earn most of their income from unskilled labor and spend almost 90% of it for food, most of their consumption is home-produced. These households receive the majority of public transfers. The second-largest and -poorest group are self-employed micro-entrepreneurs. These earn most of their income from entrepreneurial activities and re-

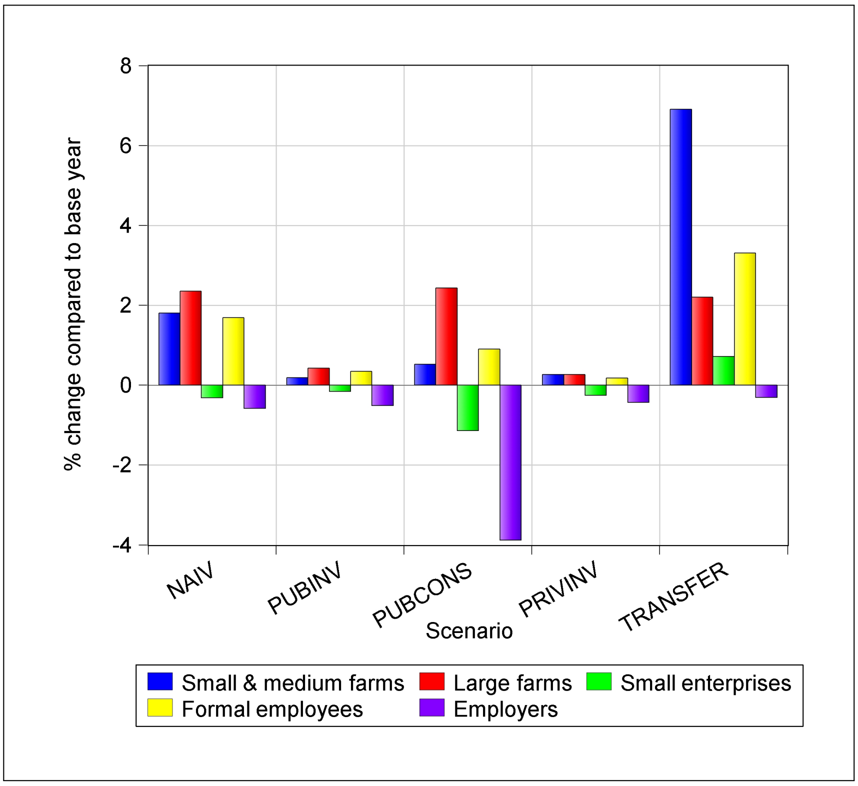


Figure 2.8.: Effects of aid on household incomes

ceive only a minor part of public transfers. Home production is of less importance in their consumption bundle which has a high share of food as well. Households of formally employed constitute another fifth of the Zambian population. These households earn income from labor and entrepreneurial activities and receive a substantial amount of public transfers, too. Large-scale farmers and employers constitute the richest part of the population. While large farm households generate income from both forms of labor and to a smaller extent from capital and entrepreneurial activity, employers receive most of their income from enterprise earnings. Both spend less than half of their income on food.[22]

[22] Concerning income distribution across household types several relevant aspects are included in the CGE, such as changes in all goods prices, factor prices and incomes. Furthermore we include household-type specific consumption patterns and factor endowments. Finally the importance of home produced and consumed food is fully taken into consideration. Nevertheless, the distributional results have to be interpreted with some caution. The five different household types represent extremely different shares of the Zambian population. A comprehensive assessment of the distributional impact requires data on the basis of deciles of the population.

2.6.2. Demand-driven effects with imperfect factor mobility

The previous section showed that additional aid inflows induce a downward pressure on domestic exports - in the Zambian case mainly copper. These effects are strongest if the spending strategy of the government focuses on non-tradeables. The effects are still noteworthy if the government spends parts of the additional income on (tradeable) capital goods. These strong shifts in the sectoral production structure and the real exchange rate appreciation are mainly driven by production factor reallocation from the tradeable to the non-tradeable sectors (see figure 2.5).

It is plausible to assume that unskilled labor is mobile across sectors in Zambia, given the very low qualification of the majority of the Zambian labor force (more than 98% of the labor force in our dataset do not have finished a secondary school) and most sectors, especially the agricultural sectors, are labor-intensive. In contrast to labor, capital might, in some sectors, be sector-specific. In the Zambian case this is of special importance given the high dependency of the Zambian exports on copper and copper products. Capital in mining may be assumed to be (at least partly) sector-specific. In contrast to other countries where exports often rely on labor-intensive goods and Dutch Disease is driven by a movement of labor [see e.g. Barder, 2006; Bandara, 1995], the reallocation effect might be overestimated in the scenarios described above, given the importance of capital for Zambian exports. For these reasons we rerun our simulations with capital in mining being fully sector-specific.

Looking at the sectoral production effects of a 45% increase in aid with mining-specific capital, Dutch Disease effects are slightly reduced compared to figure 2.4. The size of the sectoral reallocation in total is smaller and the negative effect on mining disappears. Still, the negative effect on agricultural exports, which are labor intensive, even increases. The burden of adjustment has now shifted to another export sector - from mining to agriculture. This effect is most pronounced in the transfer scenario where agricultural exports fall by more than 12%.

Given the importance of copper for the Zambian trade balance it is not surprising that with unchanged copper production, the aggregate trade balance effect shown above is also reduced. The inflowing foreign exchange is now in most scenarios used for an increase in imports instead of a reduction in exports. The qualitative ordering of the tradebalance effects across policy scenarios remains unchanged.

Regarding welfare total expenditure (TOTEXP) remains unchanged compared to the scenarios in the previous section. In contrast, the Hicks' equivalent change in welfare is higher in all scenarios compared to above especially in the TRANS scenario. This increased real welfare effect results from the fact that prices are less affected in this case and thus the spending effect leads to a higher real effect on welfare. However, the result remains that the scenarios with weaker Dutch Disease (PUBINV and PRIVINV) also

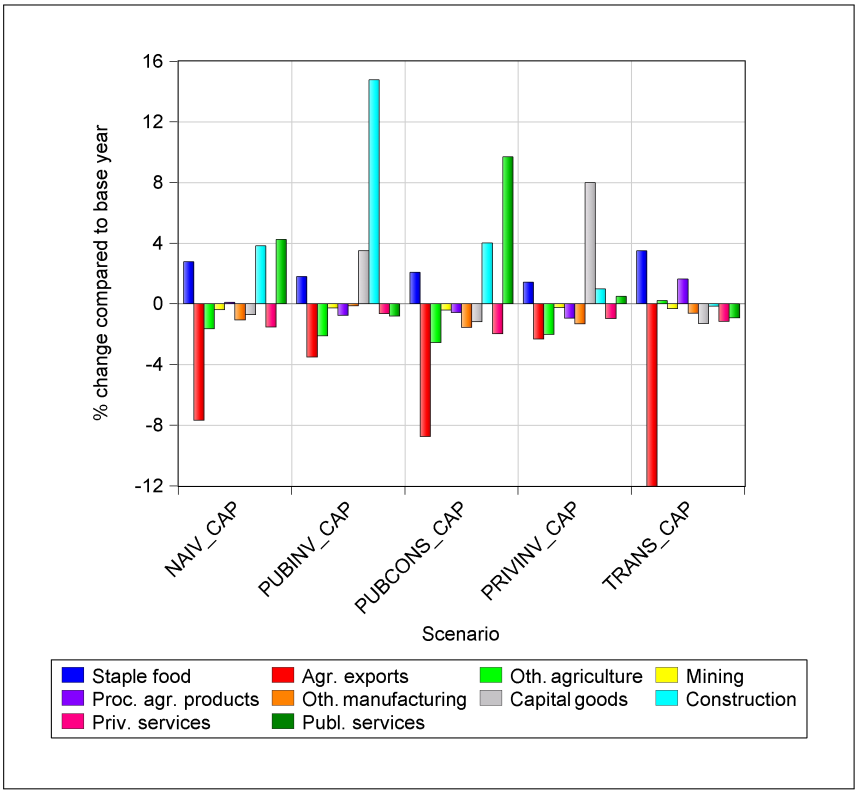


Figure 2.9.: Effect of aid on sectoral production with mining-specific capital

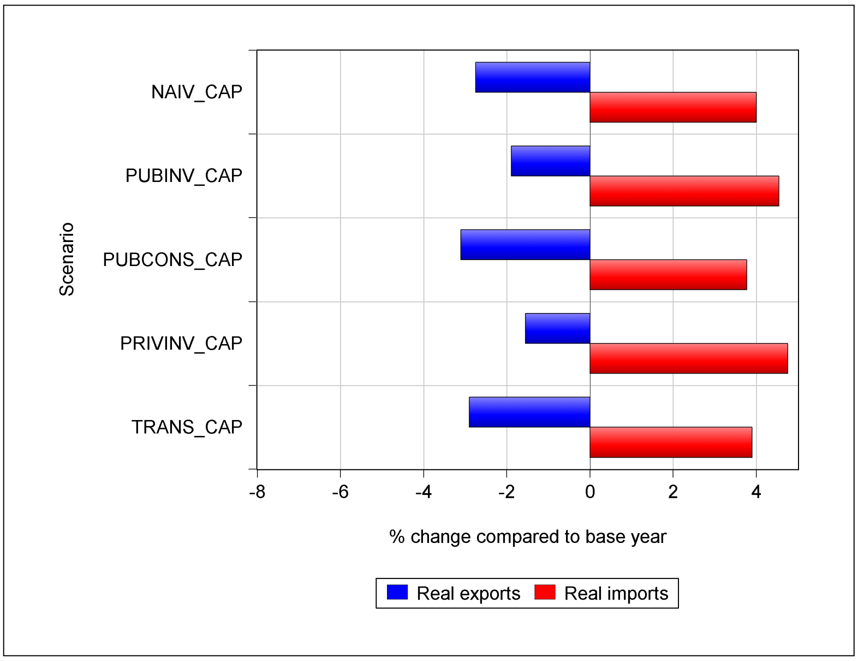


Figure 2.10.: Effect of aid on the trade balance with mining-specific capital

come with a smaller increase in welfare.[23] The increased aggregate welfare is distributed differently across households. In comparison to the scenarios with mobile capital the distribution hurts owners of small and medium farms in all scenarios except for the transfer scenario. Thus, if capital owners suffer with mobile capital, land owners suffer if capital in mining is fixed. This can be explained by the strong pressure on agricultural exports that leads to a downward pressure on land rents.

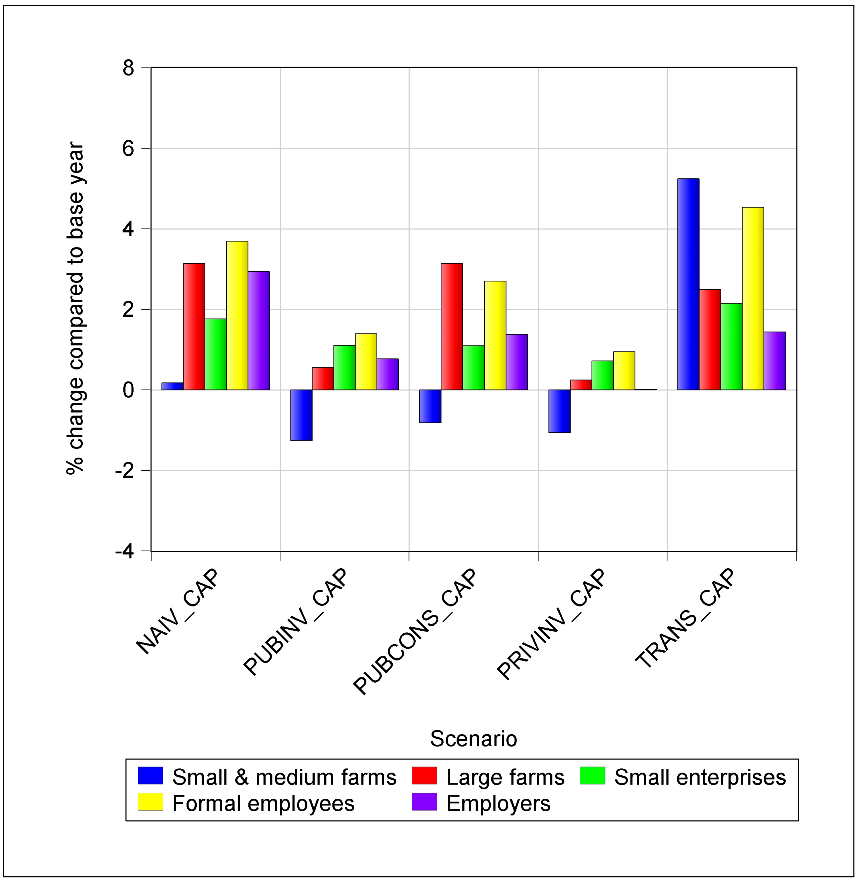


Figure 2.11.: Effects of aid on household incomes with mining-specific capital

Briefly summarized we find that in the special case of a highly specialized economy with a sector-specific factor in the main export sector, Dutch Disease effects will be less severe compared to the standard case with perfect factor mobility. Nonetheless, the conclusion remains that positive immediate welfare effects and the prevention of Dutch Disease might be conflicting policy goals. In addition in the case with sector-specific factors other exporting sectors might suffer even more and the factors used intensively in these sectors face declining returns.

[23]See figure 2.16 in the appendix.

2.6.3. Productivity (supply) effects

Adam & Bevan [2006] and Agenor *et al.* [2008] argue that aid-induced Dutch Disease effects may be compensated by large positive effects on the supply side as the overall productivity rises. They assume that aid is used for the provision of public infrastructure which increases the labor productivity as well as the access to markets. We therefore introduce a productivity response to public investment. This is relevant in the budgetary support scenario (NAIV) and in the public investment scenario (PUBINV). We present the respective reference cases without productivity effects from the previous section and add two productivity simulations for each of the two scenarios. If some or all aid is invested and if public investment is assumed to have a stimulating effect on total factor productivity, it has positive effects on GDP. This holds even if only a small part of the aid is invested, like in the scenarios NAIV_LOW and NAIV_HIGH in which only 24% of the additional aid are invested. Unsurprisingly, the effect on real GDP is strongest in the case in which all additional aid is invested and where total factor productivity is expected to have a high elasticity of 0.25 with respect to public investment (scenario PUBINV_HIGH).

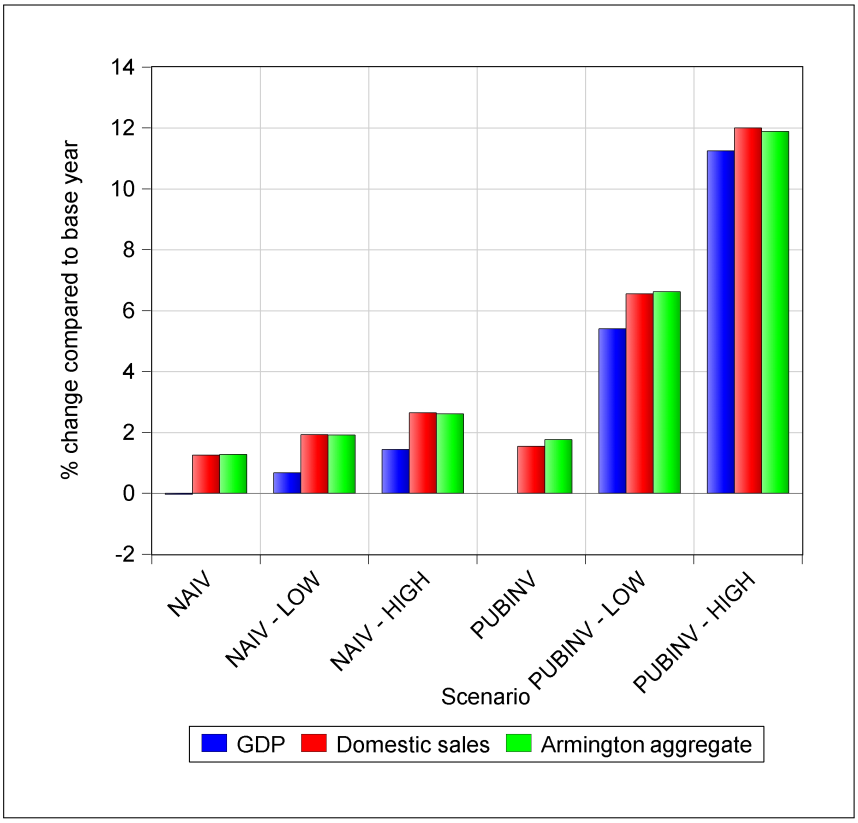


Figure 2.12.: Effect of aid on output with productivity effects

The enhanced productivity alleviates the restriction on factor supply and hence dampens the rise in the prices of increasingly demanded goods. The real exchange rate response to aid should therefore be weakened in these scenarios. Even though the real appreciation is less severe if aid is assumed to enhance productivity, the effect is not overturned. This stands in contrast with Adam & Bevan [2006] where much stronger productivity effects are assumed and a real depreciation occurs in some cases.

The aggregate results show that the Dutch Disease effects are not fully neutralised. This is also confirmed at the disaggregate level. A general production effect across all sectors is only found as long as all aid is invested and generates large productivity effects. However, even in the scenarios with productivity effects, the exporting sectors benefit only underproportionately from aid. Figure 2.13 shows the effects on sectoral production.

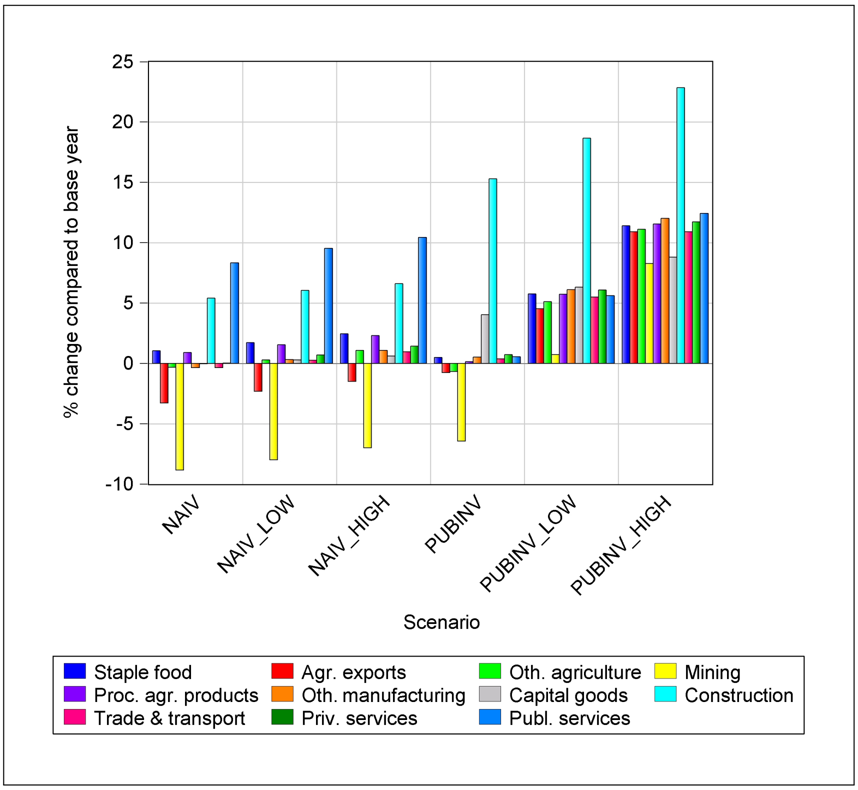


Figure 2.13.: Effect of productive aid on sectoral production

The productivity gain from public investment allows for a general increase in production. As a consequence exports may rise in line with imports. This is illustrated in two cases in figure 2.14. It is shown that positive effects on exports require a high proportion of aid spent on investment accompanied by sufficiently strong productivity effects.

Figure 2.17 in the appendix shows the effects on welfare and income distribution. The strength of the income effect depends positively on the share of international aid going into public investment and on the assumed strength of the productivity response. Similarly the likelihood of individual household types to face a real decline in income decreases. Small farm households receive a substantial amount of transfer income which is independent from the level of productivity. Therefore, these households improve their

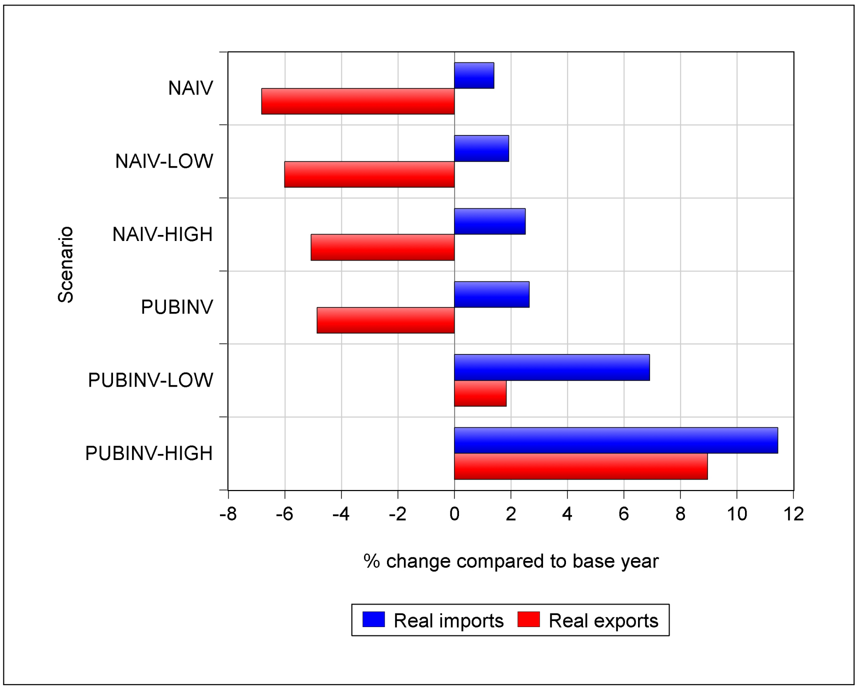


Figure 2.14.: Effect of productive aid on the trade balance

relative position in the budgetary support scenario. In contrast, the other household types predominantly receive factor incomes which rise in line with productivity. Hence, the relative position of employees, employers and self-employed households improves with the strength of the assumed productivity effects and the share of public investment. It can be concluded that the government may have to compensate poor rural households if it invests most of the aid productively.[24]

2.7. Conclusions

This paper evaluates by means of a multi-sector-multi-household CGE model for Zambia the aggregate and sectoral effects of international aid, its trade balance effects as well as the implications for welfare and income distribution. At the aggregate level, the effect of international aid on production is generally fairly small, unless a high proportion of aid is invested and leads to gains in total factor productivity. If aid is spent for other purposes, it clearly induces considerable Dutch Disease effects, especially in case that factors are mobile.

While the spending of aid leads to an expansion of some sectors in the economy, in particular the production of non-tradeable goods, it generally hurts the exporting sectors via a substantial real appreciation. A more detailed analysis of sectoral reallocation shows that the most important export sector *mining* suffers strongly from the real ap-

[24]The distributional results from the public investment scenarios are consistent with those in Adam & Bevan [2006].

preciation and the migration of its production factors to other sectors. Even if the total effective supply of factors increases due to public investment and gains in total factor productivity, the mining sector benefits only underproportionately and experiences a relative decline. As this sector is quantitatively very significant for the Zambian economy this effect should be taken very seriously. These simulation results for production and trade generally lend support to the view of Heller [2005] who calls for aid being used to eliminate bottlenecks on the supply side by investment and increased imports of capital goods. A high proportion of aid should be invested with the particular aim to enhance productivity. Moreover, the investment projects ought be targeted in favor of the exporting industries in order to reduce Dutch Disease effects. However, in recent years the Zambian public capital formation has stagnated or even decreased relative to GDP even though aid and GDP have increased.

Dutch Disease effects are less pronounced if in the main export sector, the main production factor is sector-specific. This holds in particular if we assume mining-specific capital, which limits the movement of factors to non-tradeable sectors. This assumption is implausible for the other important export sector, agriculture, which mainly employs mobile unskilled labor. For this reason the burden of adjustment shifts to those exporting sectors that predominantly employ mobile factors.

Given the growing importance of budgetary support in the Zambian aid receipts, the scenarios with a mixed spending pattern have to be regarded as most realistic. If aid leads to a proportional increase in all public spending categories, direct positive effects from increased demand are largely compensated at the aggregate level by negative effects in the two main export sectors. Note, however, that there is a direct effect on private welfare due to increased direct transfers to households. Looking at the pure public consumption strategy the simulation results illustrate that it has neither positive effects on production nor on household welfare.

The distributional results vary significantly across simulation scenarios depending on the type of spending and the assumed strength of productivity effects. While an increase in public transfers favors predominantly the poor rural households, we find that the benefits of public investment spread more evenly across the household types. In the scenarios with public investment and productivity effects households which earn income from entrepreneurial activities (self-employed and employers) are better off. In comparison with Adam & Bevan [2006] who find that rural households are always relatively worse off, our setup shows that the income effect of rural households depends on the assumptions concerning the spending pattern and the size of productivity effects.

In summary, our CGE framework allows for a comprehensive assessment of aid effectiveness on the basis of three sets of indicators: Aggregate and sectoral production, trade balance and welfare and income distribution. The simulations reveal a fundamental policy trade-off. A pro-growth-pro-trade-strategy calls for an investment-focused spending pattern which, however, does not immediately improve the economic situation of the poorest income groups. In contrast, a public-transfer-scenario immediately changes the situation of the poorest households for the better without any lasting growth effects. Policy makers in developing countries as well as international donors have to decide between short-term and long-term objectives.

A. Appendix

A.1. Descriptive statistics of the Database

Table 2.2.: Structure of production and demand in Zambia 2001

Sector	Share in total output	Share in priv. consumption	Share in total dom. demand
Staple Food	7.74%	17.57%	3.53%
Agr. Exports	1.53%	0.00%	0.84%
Oth. Agriculture	7.34%	16.24%	4.90%
Mining	7.71%	0.00%	1.10%
Processed Agr.	14.54%	33.56%	15.97%
Oth. Manufact.	10.46%	13.00%	14.26%
Capital Goods	5.56%	0.00%	11.76%
Construction	4.53%	0.70%	4.47%
Trade and Transport	22.83%	7.63%	24.20%
Priv. Services	10.05%	4.76%	11.38%
Publ. Services	7.71%	6.53%	7.59%

Table 2.3.: Structure of trade in Zambia 2001

Sector	Share in total exports(%)	Share in total imports(%)	Exports/Output (%)	Imports/Demand (%)
Staple food	0.08	0.11	0.12	0.63
Agr. exports	8.34	1.50	64.03	16.70
Oth. Agriculture	3.74	3.94	5.97	14.86
Mining	59.01	1.36	89.69	3.45
Processed agr.	2.06	12.28	1.66	15.24
Oth. manufacturing	20.09	29.68	22.51	36.00
Capital goods	0.68	31.66	1.44	53.79
Construction	0.00	0.00	0.00	0.00
Trade and transport	0.00	8.67	0.00	7.20
Private services	5.99	10.81	6.98	18.02
Public services	0.00	0.00	0.00	0.00
All sectors	100.00	100.00	17.49	15.08

Table 2.4.: Household groups and characteristics

	Small and medium farms	**Large farms**	**Self-employed**	**Formally employed**	**Employer**
% of population	57.5	0.1	21.5	20.0	0.9
% of total priv. income	26.2	1.0	20.6	33.8	12.8
Income tax rate	0.0	12.1	5.4	11.8	22.2
Savings rate	0.1	1.3	0.9	1.4	3.1
% of publ. transfers	40.1	0.0	19.0	38.1	2.9
Income from... (%)					
Unskilled labor	73.0	39.8	14.4	34.2	4.8
Skilled labor	3.6	35.9	2.6	18.9	3.1
Capital	11.1	4.1	0.6	0.3	0.08
Land	3.9	1.5	0.2	0.1	0.0
Enterprise	0.0	18.6	78.4	41.1	90.7
Publ. transfers	5.8	0.0	2.6	4.0	1.2
Expenditure (%)					
Home production	61.0	43.2	12.8	4.1	3.2
Food	87.9	49.6	65.3	58.5	40.7

A.2. Simulation results

Selected result tables

Table 2.5.: External balance (real, in billion ZK) and real exchange rate

Scenario	Real exchange rate, output-weighted	Real exchange rate, export-weighted	Export	Import	Real trade balance
base	1	1	3759.553	5901.883	-2142.330
NAIV	1.023	1.056	3506.887	5988.516	-2481.630
PUBINV	1.019	1.056	3580.163	6061.793	-2481.630
PUBCONS	1.024	1.060	3475.346	5956.975	-2481.630
PRIVINV	1.011	1.029	3608.972	6090.602	-2481.630
TRANS	1.023	1.049	3531.944	6013.574	-2481.630
NAIV_CAP	1.063	1.033	3656.368	6137.998	-2481.630
PUBINV_CAP	1.050	1.040	3688.418	6170.047	-2481.630
PUBCONS_CAP	1.068	1.034	3642.757	6124.387	-2481.630
PRIVINV_CAP	1.038	1.015	3701.142	6182.772	-2481.630
TRANS_CAP	1.057	1.031	3650.525	6132.154	-2481.630
NAIV_LOW	1.022	1.054	3537.429	6019.059	-2481.630
NAIV_HIGH	1.021	1.052	3572.337	6053.966	-2481.630
PUBINV_LOW	1.014	1.042	3831.325	6312.954	-2481.630
PUBINV_HIGH	1.009	1.030	4098.322	6579.952	-2481.630

Table 2.6.: Sectoral production (real, in billion ZK)

Scenario	Staple food	Agr. ex-ports	Oth. agricult.	Mining	Proc. agr. prod.	Manu-factu-ring	Capital goods	Con-struc-tion	Trade & Transp.	Oth. Ser-vices	Public Ad-min.
base	2480.56	489.69	2354.82	2473.80	4663.30	3355.77	1781.86	1452.78	7319.25	3223.73	2471.15
NAIV	2507.30	473.18	2346.26	2242.54	4705.54	3357.84	1781.04	1531.09	7295.74	3227.49	2675.16
PUBINV	2493.40	485.64	2338.07	2302.39	4669.97	3387.29	1853.40	1674.99	7349.49	3249.58	2483.78
PUBCONS	2498.74	487.01	2321.11	2205.97	4671.51	3339.03	1771.53	1537.72	7249.51	3213.92	2827.34
PRIVINV	2489.00	488.38	2339.41	2326.36	4660.83	3344.73	1932.89	1470.20	7386.55	3234.99	2496.31
TRANS	2536.38	437.56	2393.40	2289.41	4783.47	3371.84	1768.09	1459.70	7352.49	3234.77	2489.04
NAIV_C	2549.25	452.07	2316.34	2464.30	4668.49	3320.24	1769.29	1508.38	7301.45	3174.64	2576.38
PUBINV_C	2525.31	472.50	2305.22	2467.07	4627.65	3351.49	1844.11	1667.45	7339.47	3202.92	2451.24
PUBCONS_C	2532.22	446.87	2294.94	2463.53	4636.47	3303.70	1760.80	1511.27	7259.90	3160.37	2711.11
PRIVINV_C	2516.23	478.37	2307.54	2467.81	4619.47	3311.38	1924.33	1467.16	7372.77	3192.45	2483.31
TRANS_C	2567.27	426.07	2359.80	2465.79	4739.78	3335.08	1758.90	1450.40	7344.70	3186.51	2448.55
NAIV_L	2523.87	477.96	2361.05	2263.32	4735.00	3380.37	1786.58	1540.81	7340.44	3248.57	2705.95
NAIV_H	2542.22	482.08	2379.56	2287.98	4770.62	3406.04	1792.44	1548.86	7392.26	3272.45	2728.43
PUBINV_L	2623.75	511.68	2474.92	2482.19	4929.97	3572.25	1894.11	1724.14	7723.94	3421.02	2609.51
PUBINV_H	2763.60	542.99	2616.27	2671.33	5201.79	3767.86	1938.58	1784.84	8119.33	3602.99	2778.27

Table 2.7.: Factor prices (relative to benchmark)

Scenario	Unskilled labor	Skilled labor	Capital in mining	Capital	Land
base	1.000	1.000	1.000	1.000	1.000
NAIV	1.040	1.046		1.002	0.880
PUBINV	1.026	1.023		1.007	0.769
PUBCONS	1.044	1.069		1.003	0.611
PRIVINV	1.022	1.016		1.002	0.813
TRANS	1.040	1.017		0.999	1.573
NAIV_CAP	1.092	1.101	0.928	1.087	0.050
PUBINV_CAP	1.066	1.070	0.949	1.073	0.037
PUBCONS_CAP	1.093	1.126	0.922	1.094	
PRIVINV_CAP	1.057	1.060	0.952	1.059	0.147
TRANS_CAP	1.084	1.067	0.938	1.070	0.800
NAIV_LOW	1.039	1.047		1.002	0.865
NAIV_HIGH	1.038	1.047		1.002	0.870
PUBINV_LOW	1.018	1.015		1.005	0.863
PUBINV_HIGH	1.011	1.013		1.004	0.900

Table 2.8.: Real disposable income by household type (in billion ZK)

Scenario	Small and medium farms	Large farms	Self employed	Formally employed	Employers
base	3094.239	122.930	3035.708	3741.503	861.178
NAIV	3150.066	125.859	3026.513	3806.068	856.391
PUBINV	3099.931	123.464	3031.249	3755.477	856.810
PUBCONS	3110.450	125.948	3001.481	3776.537	827.997
PRIVINV	3102.499	123.261	3027.952	3748.366	857.345
TRANS	3307.979	125.662	3057.588	3866.158	858.565
NAIV_CAP	3099.662	126.789	3089.017	3879.477	886.422
PUBINV_CAP	3055.256	123.606	3069.213	3793.461	867.793
PUBCONS_CAP	3068.728	126.782	3068.883	3842.319	873.029
PRIVINV_CAP	3061.235	123.231	3057.317	3776.859	861.296
TRANS_CAP	3256.520	125.990	3100.767	3911.02	873.498
NAIV_LOW	3168.681	126.242	3047.980	3822.656	863.000
NAIV_HIGH	3190.287	127.195	3071.690	3850.491	870.000
PUBINV_LOW	3255.517	130.478	3204.943	3962.810	919.367
PUBINV_HIGH	3420.053	137.795	3386.004	4176.547	973.033

Table 2.9.: Production, consumption and welfare (real, in billion ZK)

Scenario	Marketed production	Private consumption	GDP	Armington supply	Aggregate consumption
base	29567.19	10740.58	12052.09	32586.4	12444.25
NAIV	29638.67	10849.92	12047.93	33007.12	12744.81
PUBINV	29787.23	10751.95	12052.61	33167.64	12466.68
PUBCONS	29627.18	10727.43	12045.58	32990.38	12781.72
PRIVINV	29672.31	10744.44	12053.08	33057.74	12472.16
TRANS	29596.16	11100.97	12048.80	32967.9	12793.49
NAIV_CAP	29570.34	10966.39	12050.56	32947.33	12755.97
PUBINV_CAP	29735.08	10794.35	12053.52	33122.71	12474.79
PUBCONS_CAP	29567.39	10864.76	12048.20	32940.47	12794.23
PRIVINV_CAP	29628.11	10764.96	12053.86	33019.86	12479.26
TRANS_CAP	29545.44	11152.81	12051.27	32923.49	12802.27
NAIV_LOW	29842.40	10913.58	12133.15	33215.48	12834.66
NAIV_HIGH	30062.29	10994.68	12225.59	33440.68	12932.39
PUBINV_LOW	31330.38	11358.13	12702.91	34748.91	13155.09
PUBINV_HIGH	33005.05	11978.45	13407.11	36463.81	13899.52

Selected figures

Figure 2.15.: Effect of non-productive aid on real gdp

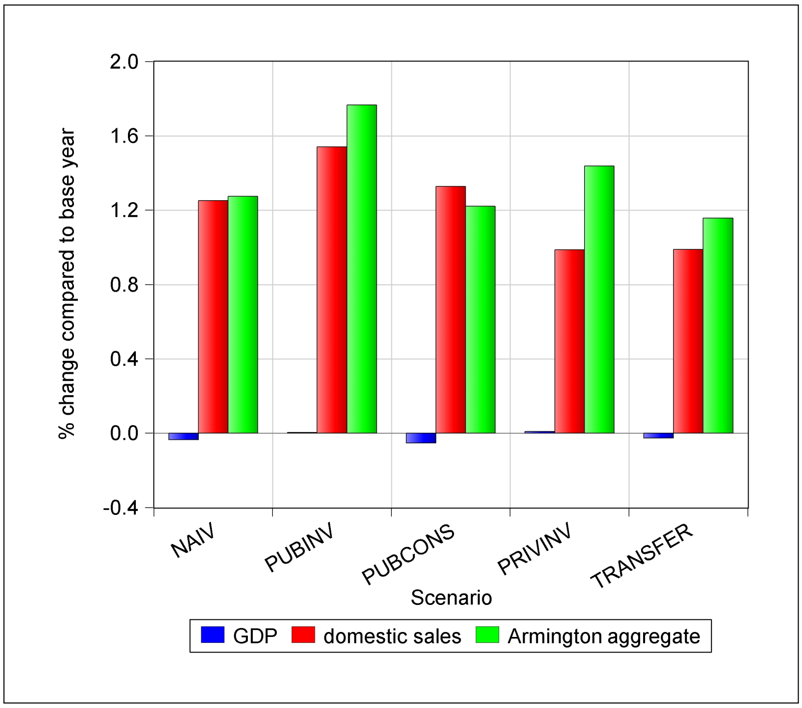


Figure 2.16.: Effect of aid using alternative welfare measures with mining-specific capital

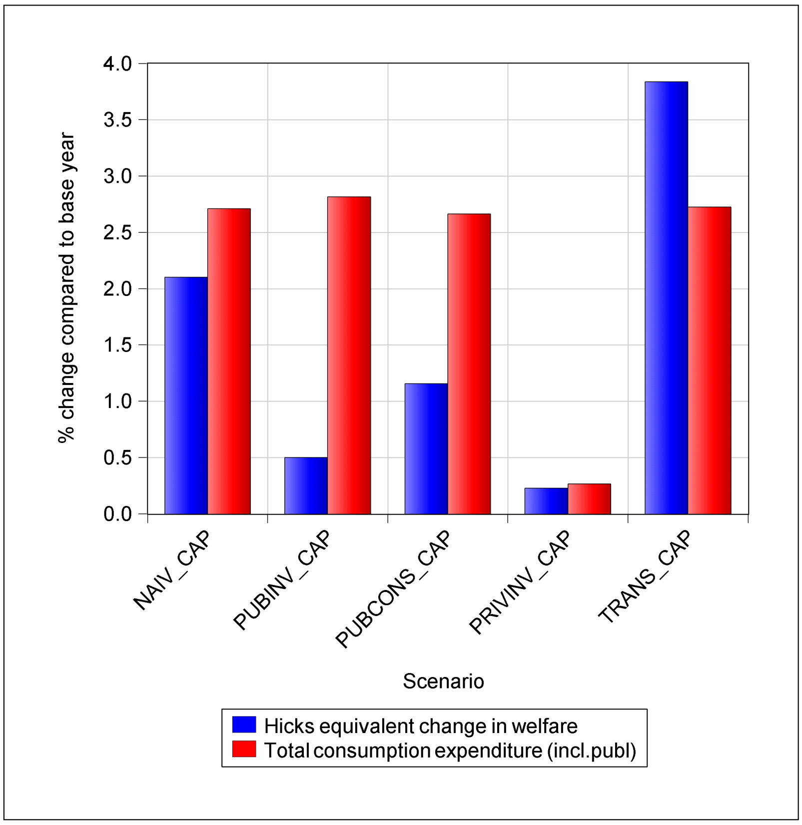
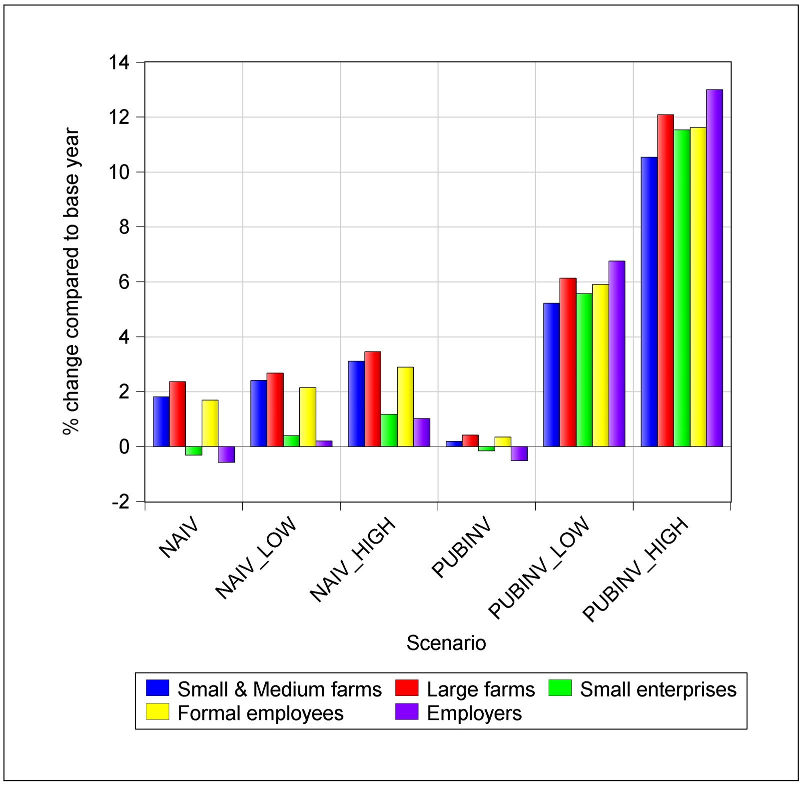


Figure 2.17.: Effect of productive aid on real household incomes



A.3. Model code listing

**Model code documentation
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3. Improving Africa's roads Modeling infrastructure investment and its effect on sectoral production behaviour

Abstract

Investment in infrastructure is considered as a crucial instrument for economic development. Given the scarce resources for public investment in developing countries policy analysis should include a detailed perspective on the effects of infrastructure. This paper develops a modeling framework for the analysis of the effects of improved road infrastructure on the economy of African countries. The theoretical framework is tested empirically and used for simulations in a Computable General Equilibrium (CGE) model. The effects on production and welfare are analyzed. Additionally, the model serves to investigate the effect of roads on the economic participation of rural households.

Working paper version published in: Proceedings of the German Development Economics Conference, Research Commitee for Development Economics, Verein für Socialpolitik, 2010

Proceedings of the Global Trade Analysis Project (GTAP) Conference, Venice, 2011

" I HAD OCCASION TO JOIN MANY SUCH FARMERS AT A 'DRINKING BASH' AND WHEN I ASKED THEM WHY THEY HAD NOT TAKEN THEIR SURPLUS GRAIN TO MARKET RATHER THAN USING IT TO PREPARE LIQUOR, THEY TOLD ME THE ROADS WERE TOO POTHOLED TO MAKE THIS FEASIBLE." *Letiche [2010]*

3.1. Introduction

Investment in infrastructure in general and in transport, water and energy in particular, is considered as a crucial prerequisite for sustainable economic development. This common belief is reflected in a strong emphasis of all donors, especially of those of multilateral aid, on the sectors energy, transportation, water and communication. World Bank lending to Africa for these sectors amounted to 3.3 billion fiscal 2009 US-Dollars which is a doubling of infrastructure aid since 2006.

> Rural infrastructure constitutes a substantial and growing component of Bank activities. Currently, over one-fifth of Bank lending in the rural sector is spent on infrastructure.[1]

The developing world and especially the African continent has a very poorly developed and maintained infrastructure compared to middle and high income countries. On average Sub-Sahara Africa has a road density of only approximately 200 meters of paved roads per km^2 compared to 1400 meters in high income OECD countries.[2] The same applies to other forms of infrastructure such as electricity, sanitation and in-house water taps. [See Fay & Yepes, 2003]

The importance of infrastructure has been stressed in the literature since the seminal work by Aschauer [1989]. For industrial countries it is clearly documented that investment in public capital increases total factor productivity and has a positive impact on long-term output. [See e.g. Gramlich, 1994; Romp & de Haan, 2007, for comprehensive surveys of the literature.] In the development economics literature several studies investigate the effects of infrastructure on national output using replications of Aschauer's approach. However, most studies on developing countries focus on poverty and income distribution instead of output, productivity or growth. [E.g. Calderon & Serven, 2008] Even though a number of project and case studies (esp. for industrial countries) find large positive effects from infrastructure on welfare and confirm reductions in transaction costs due to better transport ways, the macroeconomic infrastructure literature and more specifically the developing country literature in this field is very heterogeneous and fails to make clear predictions on the concrete macroeconomic effects.

This paper contributes to the existing literature by showing how infrastructure investment could be modeled in a general equilibrium setup with multiple sectors and heterogenous households and by integrating the dimension of market participation of

[1] World Bank Website on the strategy for Agriculture and Rural Development, December 2009.
[2] Own calculations based on World Bank World Developing Indicators 2009.

rural households into the analysis. We focus on transport infrastructure. This paper advances a disaggregated perspective in policy analysis on infrastructure investment in developing countries especially on the effects of rural roads in Africa.

We develop a stylized general equilibrium model which integrates transportation explicitly into the supply function of a representative good. In this model setup with two goods, a consumption good and a transport good, one representative agent and two factors of production, we show that supply, production and consumption can be increased by means of reduced transport costs if transport infrastructure is improved. Easier transport of goods to markets frees up labour and capital for the use in production.

In an empirical cross-sectional analysis of the influence of transport network density on the trade and transport margin, we confirm that better transport networks reduce transport and transaction costs. Using cross-sectional data for 58 countries from all over the world and controlling for a number of country characteristics it is shown that a higher road length reduces the trade and transport margins.

We combine the stylized model and the estimation results in a CGE model which additionally includes multiple goods and households, international trade, subsistence agriculture, public investment as well as operation and maintenance (O&M) costs. General equilibrium analysis provides a good toolkit to investigate the aggregate and disaggregate effects of infrastructure investment on a sectoral basis. The complex setup of the calibrated CGE model presented here allows for the investigation of the effects of transport infrastructure on production, consumption and factor allocation. Most importantly, the model permits the investigation of the effect of a better access to markets by means of better roads on the participation of rural households in the economy. The model allows for different assumptions concerning the division of the costs and benefits from infrastructure between the different household groups. It is shown that an increased quantity of transport infrastructure increases welfare. Production and consumption rise at the aggregate and disaggregate level. However, the assumed efficiency of infrastructure provision as well as the size of O&M costs are crucial concerning the magnitude of these effects. This paper focuses on general modeling issues, but the model could easily be calibrated to other more disaggregated data and applied to specific investment programs.

Given that infrastructure in most African countries is at such a low level and many of these countries are so waste that even doubling the length of roads would leave the country with a very low network density and bearing in mind the enormous investment costs for large scale infrastructure projects, our model results might provide guidance in cases where investment programs have to make a focus. From a sectoral production perspective, we find that especially those sectors with high tranport intensities and high capital intensity benefit (mining, capital goods, utilities). Our distributional results show that the welfare distribution becomes more even if higher if rural households are targeted specifically. Taking both into account, an agriculture-based development strategy would require an investment focus on rural roads whereas this is not necessary for resource-based development (like Zambia which is the example in this aper).

3.2. Overview of the relevant literature

3.2.1. Definition and classification of infrastructure

Infrastructure is a heterogeneous concept as e.g. Calderon & Serven [2008] point out. The term infrastructure is most widely defined by Jochimsen [1966][3] as

> [...] the sum of material, institutional and personal facilities and data which are available to the economic agents and which contribute to realizing the equalization of the remuneration of comparable inputs in the case of suitable allocation, that is complete integration and maximum level of economic activities.

Even narrowing the definition to only material infrastructure as Buhr [2003] does:

> [Material] infrastructure is understood to represent capital goods in the form of transportation, education and health facilities, equipment of energy and water provision, facilities for sewage, garbage disposal and air purification, building and housing stock, facilities for administrative purposes and for the conservation of natural resources.[...]

leaves us with a number of different aspects to be considered.

Other studies use a substantially narrower definition of infrastructure like e.g. Estache [2006]:

> [...] infrastructure is defined here as all the facilities used to deliver energy, water and sanitation, telecommunication and transport services.

Not all of the elements of infrastructure are goods, there are also services and immaterial components. Furthermore, not all of these are provided publicly nor are they public goods in general. It should also be mentioned that many of these components do not fall into the category of investment. The widely-used approach to analyse infrastructure by only investigating public investment does not suit the concept of infrastructure appropriately as e.g. Calderon & Serven [2008] emphasize. Nonetheless, even in the theoretical literature *public capital* and *infrastructure* are often used as synonyms, like e.g. in Gramlich [1994]:

> Public capital consists of large capital intensive monopolies such as highways, other transportation facilities, water and sewer lines and communication systems.

[3] Translation as in Buhr [2003].

It is obvious that not all of the above mentioned components of infrastructure work in the same way in promoting growth and reducing poverty. While education and health are especially efficient in improving the productivity of labor, law and security promote the efficient allocation of capital. Energy and water are intermediate inputs in production while transport and communication improve the access to markets. This variety of effects shows that the frequently used approach to measure infrastructure by using the perpetual inventory method and hence aggregating all past public investment flows is very limited in capturing all dimensions of infrastructure. Given the fact that resources for large scale investment in infrastructure are scarce in most developing countries, it is important for prudent policy analysis to take into account the variety of distinct effects of each infrastructure category. In addition some infrastructure investments give rise to high O&M cost which should be considered either.

In this paper infrastructure is defined following Estache [2006] only comprising electricity, water, telecommunication and transport. Among these components we will concentrate on transportation infrastructure i.e. roads, railways and ports. We will show how to model its effects in a suitable general equilibrium model.

3.2.2. Theoretical background

Most previous literature states that improving the length and quality of roads and railroads would lead to higher output and lower poverty. The reasoning behind this is a combination of different positive effects. Roads in general and paved roads in particular improve the connection between producers, markets and consumers. Enhancements of the roads and railroads of a country should hence lead to a more efficient allocation of goods and services. This increased efficiency in the allocation is based on different channels[4]:

First, as transport is easier and less costly producers lose less of their production on the road and spend less time for transportation i.e. the unit transport cost per marketed unit of the produced goods decreases. This should result in a higher share of produced goods being marketed. Less production is lost on the way to the market and less is consumed directly at the producers house. Furthermore, as producers have improved access to markets they are not relying on retailers but can directly access their potential consumers, this should increase competition on markets but also the possibilities for small producers to realize "fair" prices. In addition, consumers have improved access to markets which increases the diversity of products available for consumption and reduces information asymmetries. Hence, this increases arbitrage between formerly separated markets. Moreover, as producers and consumers are linked more directly, production adapts more efficiently to demand as information flows are improved.

Olsson [2009] makes a distinction between direct and indirect effects from better roads.

[4] Based on the arguments by Olsson [2009].

The first channel above represents the direct effect whereas the three other channels constitute the indirect effects. In addition, Olsson [2009] expects that the economy undergoes structural changes as technologies spread more easily across the country. All these effects should lead to a reduction in the spread between producer price and consumer price[5]. This could either result in higher producer prices, in lower consumer prices or a combination of both. If producer prices rise this would lead to a higher share of marketed production and a lower share of home consumption leaving households with a higher income from marketing their production and the possibility to broaden the range of consumed products. A reduction in consumer prices with constant producer prices enables consumers to increase their real consumption which has a clearly positive effect on welfare.

In addition to the aggregate positive effect an improvement in the road and railroad network will have a positive impact primarily on the rural population. The agricultural sector has the highest spread between producer and consumer prices hence relative benefits for farmers should be the highest. Moreover, the rural population is typically spread across wide areas with very limited access even to local or regional markets leaving this part of the population with limited consumption and income opportunities. In addition, better roads improve the access to health care and educational institutions for the rural population.

In the production function literature infrastructure is normally treated as a production factor entering the national aggregate production function. In this paper we will model infrastructure more directly as a means of transport. Infrastructure is used to transport the production to the market. Improvements in infrastructure reduce the need for labor and capital in the transportation services sector. Infrastructure enters the production function of the transportation sector and is a substitute for capital and labor in this sector but not in others. There exist large sectoral differences in transport intensities, hence, higher transport requirements of a specific good induce higher benefits from better roads for this sector.

3.2.3. Econometric studies on the infrastructure-development link

The literature on infrastructure impact is very heterogeneous in terms of what kind of infrastructure is analyzed and which outcome variable is considered. There exist several detailed surveys of the literature e.g. by Gramlich [1994]; Buhr [2003] and more recently Romp & de Haan [2007]. The following very brief summary of the relevant literature only includes the main strands of the transport literature and even more specifically the studies on the effects of transport infrastructure improvements in developing countries.

Most macroeconometric studies on the effects of infrastructure follow the so-called production function approach. They estimate a national production function where GDP or growth depend not only on labor, capital and technology but also on public capital.

[5]Both net of taxes.

Public capital is normally measured using the perpetual inventory method. Most of the recent literature in this strand is based on the work by Aschauer [1989] who applied the method to U.S. time series data. It has been applied to cross-section data including developing countries by Hulten [1996]; Ram [1996] and many others. There seems to be a consensus on the positive effect from public capital on output even though the magnitude of this effect is disputed. Still, the methodology is only capable to investigate the effect of public capital as an entity instead of the effects of distinct forms (like roads) specifically. This is for example criticized by Calderon & Serven [2008]. Hulten and also Aschauer [2000] emphasize that not only the volume of infrastructure provided but also the efficiency of its use are important. Wu *et al.* [2010] find that government spending is less effective in low-income countries and attribute this to inferior institutions.

Estache [2006] reviews the macroeconometric literature on infrastructure and development and points out that even though

> [...] since the late 1980s over 150 published papers in English, French or Spanish and at least as many unpublished ones have analyzed the macroeconomic effects of infrastructure [...]

there is still a large knowledge gap especially due to limitations in the fields of data collection, evaluation of existing projects and accountability. Estache concludes that concerning the macroeconomic output effect the findings are positive nonetheless concerning other aspects of development such as poverty and distribution there is less evidence available. Njoh [2000] emphasizes that the link between infrastructure and development has been investigated mainly for the industrial countries in the 1950s and in form of country studies. Nonetheless, he underlines the specific importance of the subject for developing countries. The findings from cross-country studies concerning poverty and distribution and its correlation with infrastructure suggest that the poor and rural population should be targeted specifically as they did not benefit from past infrastructure projects. [See Bryceson *et al.*, 2008; Letiche, 2010]

A completely detached strand in the macroeconomic literature focuses on the trade effects of better transport networks. Using gravity models, this literature investigates the tariff equivalent costs of poor roads on international trade. Unfortunately, disaggregated data for developing countries is very limited and prohibits disaggregated studies especially for rural areas in Africa and the possibility to access local markets. Examples are Yeats [1980], Limao & Venables [2001] and more recently Portugal-Perez & Wilson [2008].

In addition to the considerable macroeconomic literature there exists a variety of country and case studies evaluating specific projects or programmes in developing countries. These studies mostly focus on the effect of better roads on variables such as poverty, employment and access to markets. Examples are Olsson [2009] who analyses the Philippines, Escobal & Ponce [2002] who compare three African countries, Fan *et al.* [1999] for India or Fan [2008] for Uganda. These studies provide promising evidence about the overall positive effect of infrastructure, especially on rural development. For all of these countries it has been found that especially rural roads provide an instrument to reduce rural poverty and promote growth.

3.2.4. CGE models of infrastructure in the literature

Against the background of the presented macro- and microeconomic approaches a CGE study is not limited to only one specific outcome variable. Such a model shows the effects of a specific policy experiment on aggregate and sectoral output but also on income distribution, welfare and factor allocation as e.g. Stifel & Thorbecke [2003] emphasize. Furthermore, it allows to distinguish between direct and second round effects and it provides a clear counterfactual. Recent studies using this approach are Agenor *et al.* [2008] [applied to another country by Moreira & Bayraktar, 2008], Adam & Bevan [2006] and Levy [2006] as well as Jensen [2009].[6] These studies use quite substantially differing models: While Agenor *et al.* [2008]; Moreira & Bayraktar [2008] explicitly model all different forms of public capital and their effects, their model is very aggregated in terms of scctors and households. This model has only one representative household and only one aggregate good. The authors disaggregate the simulated macroeconomic effects from infrastructure using a dynamic microsimulation. Adam and Bevan's model on the other hand is more disaggregated with respect to the number of sectors and contains a number of different households but it includes only aggregated public capital and does not explicitly account for roads. They assume that public capital directly enters the production function. This approach could be interpreted as a CGE-replication of the production function approach in the econometric literature. A comparable approach is used by Levy [2006] who compares the effects of public investment either in the road infrastructure or in irrigation infrastructure in Chad. She confirms that road investments after a windfall gain are capable to compensate Dutch Disease effects. However, her model applies an approach comparable to the production function approach and introduces infrastructure as a multiplier on total factor productivity. Hence, it summarizes the effects from all public capital investments and does not specifically address the transport cost effect. Jensen [2009] explicitly refers to this caveat and adresses investments in road quality and road quantity by explicitly including a road network model based on the engineering literature. The economic part of his model is aggregated to a degree comparable with Adam & Bevan [2006] and Levy [2006] with five production sectors. Jensen [2009] includes the effect of roads on transport costs and welfare in a very detailed way. Unfortunately such a detailed analysis requires very detailed data which is not available for many African countries like the Chad (as in Levy's study) or Zambia (which is analyzed in this paper).

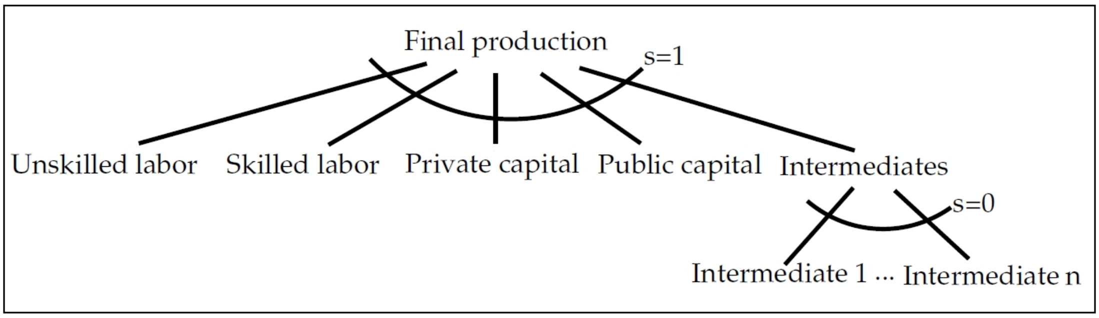
All of these models do not account for the fact that an important share of agricultural production in developing countries is directly consumed in the producer's house. This part of agricultural production is not marketed and hence does not require transporta-

[6] These are only the studies for African countries as this is the focus of this paper. It would be ideal to use a spatial multiregional CGE model with Iceberg transport costs like e.g. Buckley [1992], Bröcker [1998] and Haddad & Hewings [1999], unfortunately the regionally disaggregated data which is essential for this approach is not available for Sub-Sahara African countries.

tion i.e. infrastructure. The models by Agenor et al./Moreira/Bayraktar, Adam/Bevan and Levy do also not take into account that transport networks are of minor importance for production but are an essential requirement for market access. Hence, better roads reduce the demand for capital and labor in transportation. Our approach combines the disaggregated modeling of infrastructure as in Agenor *et al.* [2008] with the sectoral disaggreation as partly done in Levy [2006] and Adam & Bevan [2006] and additionally accounts for subsistence agriculture and O&M-costs. Our production function clearly distinguishes between production and transportation to markets as also Jensen [2009] does. It also accounts for sectoral differences in transport intensity. The general structure of production is shown in figure 3.4.

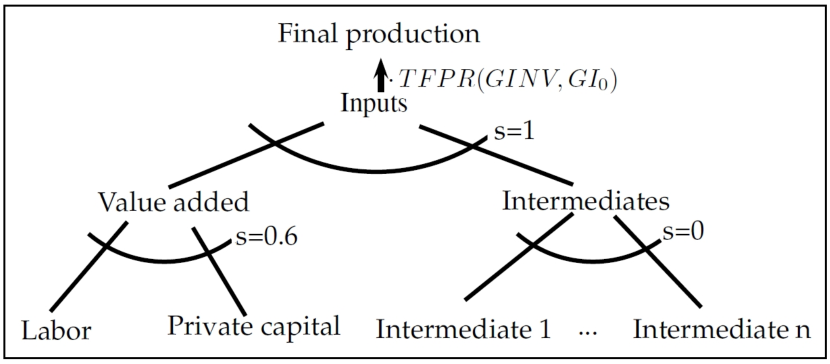
In Adam & Bevan [2006] public capital is provided by the rest of the world and enters the sectoral (Cobb-Douglas-) production functions as a factor of production. The respective exponent has been taken from an empirical study by Hulten [1996] and reflects the public capital-elasticity of output. In this setup there exists a limited possibility to substitute between labor, capital and public capital. Obviously, this aggregated approach does not capture the effects from transport networks explicitly, it summarizes the output effect of all different kinds of public investment. There are also no sectoral differences as the elasticity parameter is only available at the most aggregate level. Infrastructure in this model is just another factor of production with a particular provision (see figure 3.1).

Figure 3.1.: Production function in Adam and Bevan (2006)



Levy [2006] uses a model which is, like the model used here, based on the IFPRI model [See Löfgren *et al.*, 2002]. She introduces migration and external price setting into the model, which are special features of the Chad. Infrastructure is included in a comparable way as in Adam & Bevan [2006]: Infrastructure acts as a multiplier on all inputs in the production function. Thus, it is assumed to increase total factor productivity, which is in line with the empirical findings in the production function literature. Infrastructure increases factor productivity by the factor $GINV^{0.2}$, which means that an additional percent of infrastructure increases factor productivity by approximately 0.2 percent. The shock is applied uniformely across sectors no matter which are the concrete infrastructure requirements. Her way of modeling infrastructure is, like the one of Adam & Bevan [2006] very much in line with the empirical findings of Aschauer [1989], Hulten [1996] and others. However, it is only capable to capture the effects of public capital in general but not the distinct effects of transport infrastructure through transport costs specifically.

Figure 3.2.: Production function in Levy (2006)



Agenor *et al.* [2008] use a simulation model which includes three different forms of public capital in the national production function of a composite good: Public capital in health, education and infrastructure. These capital aggregates enter at different levels of a nested production function. Infrastructure enters the top nest. Agenor *et al.* [2008] describe the elasticity of substitution between infrastructure and the labor/capital-nest to be "low". While their model is very detailed concerning different forms of infrastructure it is limited by construction with respect to the sectoral results. The model has only one sector of production and one representative household. Hence, there is no possibility to have different transport-intensities across sectors and different sectoral reactions to an increase in infrastructure (see figure 3.3). The authors are able to disaggregate the effects of a public capital shock with respect to households and sectors using a microsimulation model. Nonetheless, this modeling procedure is not able to capture asymmetric effects in the different sectors due to differences in transport intensities.

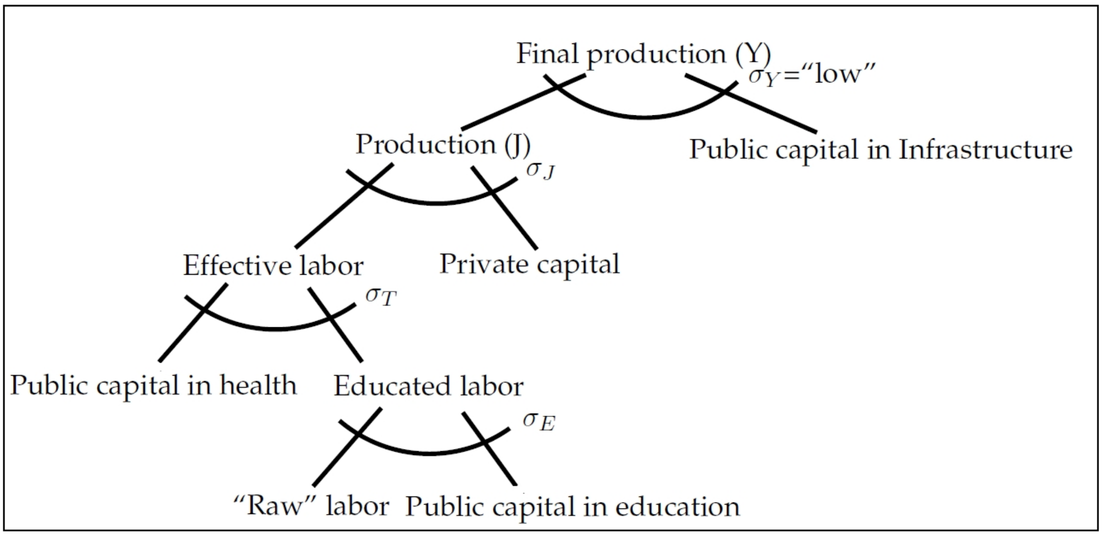
3.3. A Computable General Equilibrium model of road infrastructure

3.3.1. A stylized model including transport infrastructure

Before moving to a more realistic CGE of infrastructure, we want to illustrate in a small stylized model how the above mentioned effects from transportation are integrated into a general equilibrium model. The model is formulated as a mixed complementarity problem (MCP) which means that quantities are associated with zero-profit conditions and prices are linked with market-clearance conditions.[7] If the zero profit conditions (equations (3.1) to (3.4)) hold as strict equations a positive quantity of the respective good is

[7]See Rutherford [1999] for a detailed description of the approach and appendices 1&2 in Markusen [2004] for an illustrative application.

Figure 3.3.: Production function in Agénor et al. (2008)



supplied and demanded. The market clearance conditions (equations (3.5) to (3.10)) determine the prices that ensure that supply equals demand. An income-spending balance equation (11) closes the model.

We distinguish between the production and marketing of goods. This is important as the assumption that all production is marketed will later be relaxed and some production will remain unmarketed. Marketing requires the transport of goods by means of labor, capital and infrastructure. Poor infrastructure leads to a higher need of labor and capital used for transport. We assume that using infrastructure implies only operation and maintenance cost while using transport services means to pay for labor and capital.

We model a simple closed economy with only one representative consumption good C, two factors of production and one representative agent: The composite good (X) is produced in a standard Cobb-Douglas production function. The zero profit condition for X is given by:

$$p_X = p_L^{\alpha} \cdot p_K^{1-\alpha} \tag{3.1}$$

where p_X is the price for one unit of X, p_L the wage and p_K the capital rent with α and $(1-\alpha)$ being the input coefficients of labor and capital respectively.

The production X is then transported to the market using transportation services TS or a road. Both are combined in the transport aggregate T which is remunerated with the price p_T. The transport aggregate T is assumed to be provided in fixed proportion to the production of X. The zero profit condition for C is defined as in equation (3.2).

$$p_C = p_X \cdot \frac{X_0}{C_0} + p_T \cdot \frac{T_0}{C_0} \tag{3.2}$$

p_C being the consumption price and p_T being the unit transport cost. Prices are multiplied with the relation of production to consumption and transportation to consumption in the base year. The subindex 0 indicates base year levels. This does not imply that the demand for transportation services is fixed as transportation services and infrastructure are substitutes. The supply of infrastructure is fixed exogenously and is hence not subject to a zero profit condition.

Transport services (TS) are produced by using capital and labor while transportation via a road only requires infrastructure capital $\overline{INF}$. Hence, the zero profit condition for transport services is defined by equation (3.3) and (3.4) replaces the zero profit condition for the transport aggregate.

$$p_{TS} = p_L^{\beta} \cdot p_K^{1-\beta} \tag{3.3}$$

$$T = \frac{T_0}{X_0} \cdot X \tag{3.4}$$

The respective prices of the commodities X and TS are complementary to the market clearing conditions (3.5) and (3.6)

$$p_X \cdot X = \frac{X_0}{C_0} \cdot C \cdot \left(p_X \cdot \frac{X_0}{C_0} + p_T \cdot \frac{T_0}{C_0} \right) \tag{3.5}$$

$$p_{TS} \cdot TS = \frac{TS_0}{T_0} \cdot T \cdot \left(p_{TS}^{\frac{TS_0}{T_0}} \cdot p_{INF}^{\frac{\overline{INF}}{T_0}} \right) \tag{3.6}$$

The value of the production of X and TS respectively (left hand side of equations (3.5) and (3.6)) must equal the value of demand of the respective good, given by the right hand side of the equations. The price adjusts to fulfill this condition. Both are scaled to base year levels for reasons of simplicity.

The artificial price for the transport aggregate (p_T) is defined by the market clearance condition for transportation, the shadow price for infrastructure (P_{INF}) by the respective condition for infrastructure.

$$p_T \cdot T = \frac{T_0}{C_0} \cdot C \cdot \left(p_X \cdot \frac{X_0}{C_0} + p_T \cdot T_0 C_0 \right) \tag{3.7}$$

$$p_{INF} \cdot \overline{INF} = \frac{\overline{INF}}{T_0} \cdot T \cdot \left(p_{TS}^{\frac{TS_0}{T_0}} \cdot p_{INF}^{\frac{\overline{INF}}{T_0}} \right) \tag{3.8}$$

The prices for labor and capital result from the respective market clearing conditions (3.9) and (3.10)

$$p_L \cdot L = \alpha \cdot X_0 \cdot X \cdot p_X + \beta \cdot TS_0 \cdot TS \cdot p_T \tag{3.9}$$

$$p_K \cdot K = (1-\alpha) \cdot X_0 \cdot X \cdot p_X + (1-\beta) \cdot TS_0 \cdot TS \cdot p_T \tag{3.10}$$

Total consumption equals total income, which is defined as the sum of income from labor, capital and infrastructure.

$$p_C \cdot C = Y \tag{11a}$$

$$Y = L \cdot p_L + K \cdot p_K + \overline{INF} \cdot p_{INF} \tag{11b}$$

All other things being equal an increase in infrastructure would reduce the demand for TS as infrastructure is a substitute for transport services. The reduced demand for TS frees up labor and capital that can be used for increased production.

A natural way to calibrate this model would be to assume that in the benchmark situation the existing stock of infrastructure ($\overline{INF}$) is zero. This assumption implies that - even though there might exist a stock of infrastructure - infrastructure in the benchmark is so poor that it does not add to national welfare and that the existing trade and transport margin is an equilibrium outcome of the limited availability of roads. Investing in infrastructure would translate into a counterfactual with positive values of $\overline{INF}$ assuming that additional infrastructure allows for a reduction of spending on transport services (TS) and adds to overall welfare as it enters the national income Y.

The model represented by equations (3.1) to (11b) has been calibrated to an artificial benchmark dataset with no infrastructure and $\frac{T_0}{X_0} = 0.1$ and increases in infrastructure by 1 to 10% of GDP have been simulated. The following reactions to an increase in $\overline{INF}$ result for the different variables of the model:[8]

Variable	X	C	T	TS	p_X	p_C	p_T	p_{TS}	p_{INF}	Y
Sign of effect $\partial x / \partial \overline{INF}$	+	+	+	-	-	-	-	-	-	+

These qualitative results are robust to changes in the benchmark data as well as in the assumed increase in infrastructure. The results from simulations in the idealized model show that the general ideas described above are correctly translated into a model. Nonetheless, a number of extensions to the basic model are needed in order to draw a realistic picture of the effects of infrastructure investment and to allow for policy impact assessments. These are described in the next section.

[8] Results for p_L and p_K depend on the assumed factor intensities and are not shown here. P_K served as numéraire in this example.

3.3.2. Extensions to the small model

The model above does not take into account that there is no actual price for using the roads. The cost of roads must be divided into two categories: The investment cost that occurs before the road is in place and the maintenance cost; both must be accounted for as costs for the economy. It is very likely that the actual cost of road usage is far below the cost of transport services. Nonetheless, the price for transportation services in the model reflects the alternative cost or shadow price of infrastructure. It may be interpreted as the welfare gain from increased infrastructure. This approach, to measure the gains from infrastructure by using the willingness to pay for roads, is for example used by Olsson [2009] and we adopt this interpretation here.

An important feature of CGE models is that they integrate heterogeneous households and different goods. This allows different transport intensities across sectors. In addition it is very likely that welfare increases from better roads are particularly beneficial for the rural population. This can be implemented in the model by assuming that the financing of roads is done via taxes proportional to the income of households but the benefits are assigned to households with respect to their location.

An important issue for developing countries is the notion of subsistence agriculture or in general home consumption of households' own production. The decision to either sell their production on markets or directly use it at home will significantly depend on the costs a household would have to bear to transport their goods to the market and their purchases back home. Therefore, the decision between home consumption and marketing of produced goods should be modeled explicitly, this is done here, as shown in figure 3.4.

In the small model it is implicitly assumed that one additional unit of infrastructure investment provides exactly one additional unit of road which can only be used for a limited number of goods to be transported. In the CGE model roads are public goods in the way that one additional kilometer of roads may be used to transport a large number of different goods. This is done by a multiplier on infrastructure based on empirical findings.

3.3.3. The Computable General Equilibrium model

The general idea shown in the small model above is translated into a disaggregated CGE model.[9] The model is structured as follows:

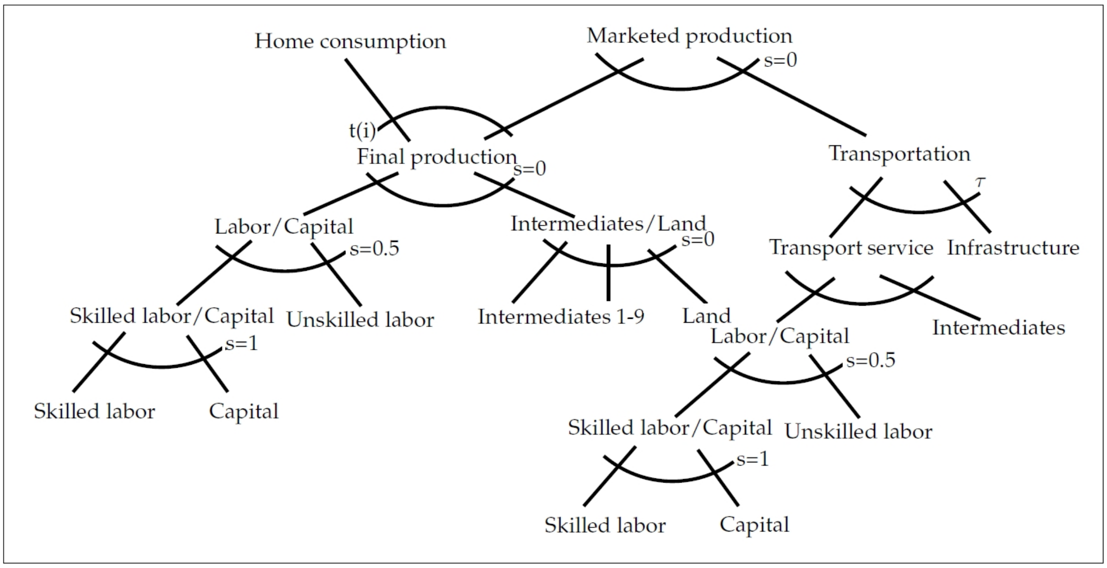
Production

Production is disaggregated into nine sectors, two of which are agricultural, four industrial and three are services. In each sector output is produced from a specific combination

[9]The general structure of the model presented here is comparable to other developing country CGEs like e.g. the IFPRI model. The model has been programmed using MPSGE and solved using the GAMS/PATH solver. A copy of the model code can be made available on request.

of intermediate inputs, capital and two different types of labor. Labor and capital are assumed to be mobile across sectors. The production process is modeled using a nested production function as shown in figure 3.4.

Figure 3.4.: Nested production function

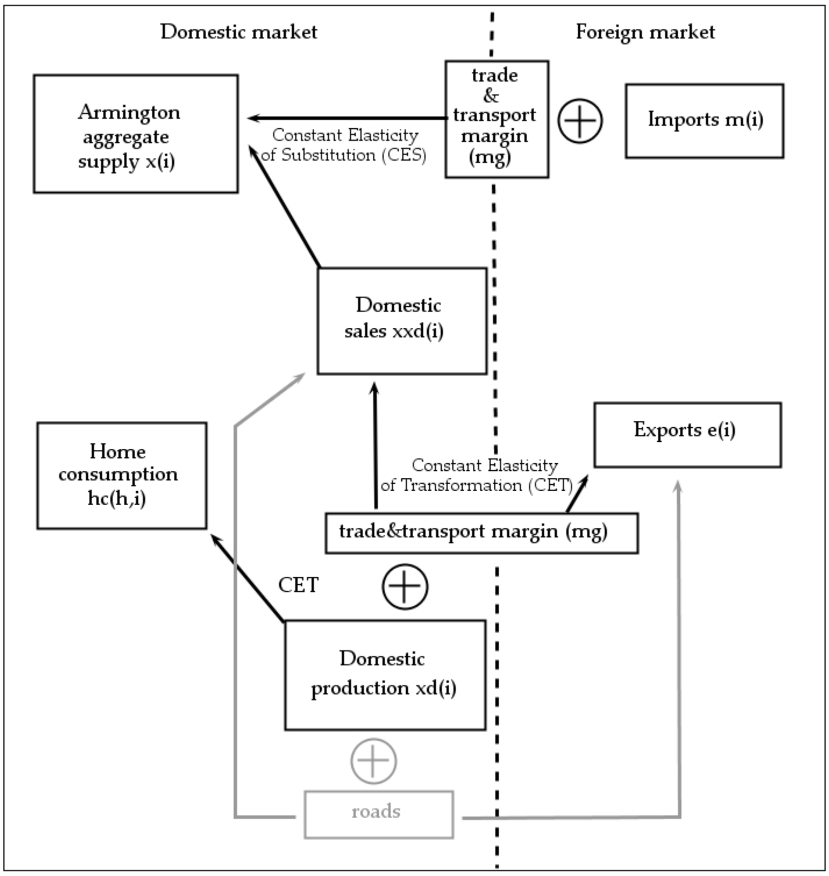


Skilled labor and capital are imperfect substitutes in a Cobb-Douglas production function with a corresponding elasticity of substitution (s=1). We assume the substitutability between unskilled labor and skilled labor/capital to be more limited (s=0.5). Substitution between different intermediates or between intermediates and factors of production is ruled out by the assumption of a Leontief type top nest (s=0). The supply of labor, capital and land is fixed exogenously to base-year levels.

Domestic production may either be marketed or consumed at home. If it is marketed, it has to be combined with a transport good, which might either be trade and transport services (*mg*) or a road (which is initially not available and shown in grey color in figure 3.5 below). The choice between *home consumption* and marketed production is determined by a constant elasticity of transformation (CET) function. Home consumption is only possible in agricultural sectors and basic manufacturing (i.e. food processing). Domestic goods are imperfect substitutes for foreign goods. Domestically produced goods are combined with imported supply in a Constant Elasticity of Substitution (CES) function to form the Armington aggregate which is sold on domestic markets. Domestically produced goods may also be exported, but production of exports differs from production for local markets. This is implemented using a Constant Elasticity of Transformation (CET) function. The structure of the supply side is shown in figure 3.5.[10]

[10]The Armington elasticities have been taken from the literature. See the appendix for details.

Figure 3.5.: Supply side of the economy



Infrastructure serves as an input in the production sector *road*. Infrastructure capital is combined with O&M, which is paid for by the government, to provide an alternative way of transporting goods to the market. The resulting *transport good* is a perfect substitute for the *trade and transport margin*. Nonetheless, the supply of this alternative transport is limited by the supply of infrastructure capital. Transport via roads is remunerated with a shadow price that represents the welfare gains in terms of savings in time, capital and goods. These gains are either assigned (i.e. transferred) to all households proportionately, only to rural households or to the government. This last case will be used as benchmark scenario.

Demand

Domestic demand consists of household demand, government consumption, investment and intermediate demand. Intermediate demand is linearly linked to the quantity of output.

The model has two household types which differ in their location: urban and rural. The two household types also differ in their factor endowments, their savings, direct tax rates and consumption preferences. Households generate income from labor and capital. Apart from these income sources households receive transfers from the government. Household income is used for tax payments, consumption and savings.

The government generates income from taxes, public capital and international aid. It spends its revenue on public consumption, transfers to households, interest payments to the rest of the world, public investment and operation and maintenance of roads. Transfers, subsidies and interest payments are fixed exogenously. The only good the government buys apart from the public investment good are public services. In the benchmark scenario the government collects the welfare gains from better roads through endogenous taxes and uses these additional earnings to provide a higher level of public services or transfer payments and thus redistributes the welfare gains.

Savings are generated by households and the rest of the world. Savings are used for private capital investment. The model is closed by total investment that always equals total savings. There exists only one investment good. Infrastructure capital is provided from an external source, international aid.

3.4. Empirical relationship between infrastructure and transport costs

Translating the theoretical framework into a suitable CGE model requires information on how much reduction in transport costs will result from an increase in the quantity and quality of roads. This relationship is captured by a parameter that defines how much additional transportation will be made available from a specific amount of public capital in infrastructure. This parameter must be set exogenously.

The literature is rather vague about the exactly quantified relation between increased expenditure on infrastructure and transport costs: In a case study of several international transport corridors in Africa Teravaninthorn & Raballand [2009] find that an improvement of the roads from "fair" to "good" reduces the transport cost by approximately 15%. Unfortunately, they do not provide any quantitative information on the amount of public investment needed for this improvement. The vague classification "from fair to good" does not allow to integrate this estimation into a quantitative model. In contrast, studies using the production function approach provide concrete elasticities but these are not exactly compatible with the theory developed above as they measure the output effect, which is classified here as an indirect effect from better transportation. In addition, these results differ significantly across studies. Estimations of tariff-equivalent costs of poor infrastructure in gravity models focus on *international* trade. They provide neither any estimates about *intranational* transport costs nor about concrete amounts of investment needed to provide a better road status.

Against this background this paper attempts to quantify the effect from better roads on transport costs directly. As the CGE model uses Social Accounting data it is natural to estimate the elasticity of the trade and transport margin with respect to the transport network from Social Accounting data, too. SAMs are available for a large number of countries and provide detailed sectoral information on the demand for transport services. In a cross-sectional estimation for 58 countries from all over the world we investigate the effect of transport density on the trade and transport margin. This is a straight forward way to test the aforementioned theoretical reflections and the model setup empirically and provides us with a concrete parameter estimate for policy analysis in the CGE model.

We estimate the following equation:

$$ln\, m_i = \alpha + \beta\, ln\; transport_i + \gamma_1 ln\; gdpc_i + \gamma_2 ln\; urban_i + \gamma_3 ln\; pop_i + u_i \tag{3.11}$$

As dependent variable we use sectoral spending on trade and transport services relative to sectoral output, i.e. the trade and transport margin (m_i). We calculate this output-weighted margin from input-output data both over all sectors and only for agricultural sectors. Our main independent variable of interest, the transport network density ($transport_i$), is measured here as the length of all railroads and paved roads in km per surface in km^2. In addition, we control for *GDP per capita* ($gdpc_i$) as a proxy for development of the economy and hence for the stage of market development, for the degree of urbanization ($urban_i$) as a measure of dispersion of market participants and for the size of the population (pop_i).[11]

The data on trade and transport margins comes from input-output-tables from different sources, mainly the International Food Policy Research Institute (IFPRI) and the OECD. Data on road and rail road length as well as the control variables *GDP/capita* and *population* are taken from a World Bank Dataset on infrastructure used by Fay & Yepes [2003] and from the World Development Indicators (WDI) Database for more recent years. Missing data has been taken from the Human Development Index, Eurostat, the United Nations and national statistical authorities of the different countries.

The spending for trade and transport represents between 2 and 41 % of sectoral production costs, 12 % on average. The countries in our sample have on average 570 m of transport infrastructure per km^2 of surface. The smallest country has 3.5 million inhabitants, the largest more than 1 billion. On average more than half of the population lives in towns. The GDP per capita lies between 148 US-$ and 45.478 US-$.

[11] Several other control variables such as the Human Development Index (HDI), literacy, economic freedom, surface and others have been tested but the results are not shown here as they are not qualitatively different and most variables have been insignificant. The next chapter of this thesis develops the econometric approach further.

The sample consists of 58 countries of which 28 are OECD countries, five East and South Asian countries, four eastern European and Middle-Asian countries, one middle East/North African country, nine Latin American countries and eleven countries from Sub-Sahara Africa. Five of these countries (Egypt, Russia, Bolivia, Belgium and Chile) have been excluded as outliers.[12]

Figure 3.6 shows the sectoral trade and transport margin as a share of sectoral output for one country in the sample (Zambia) in order to give a general impression of the importance of trade and transport costs in developing countries and across different sectors.

Figure 3.6.: Sectoral trade and transport margins in Zambia 2001

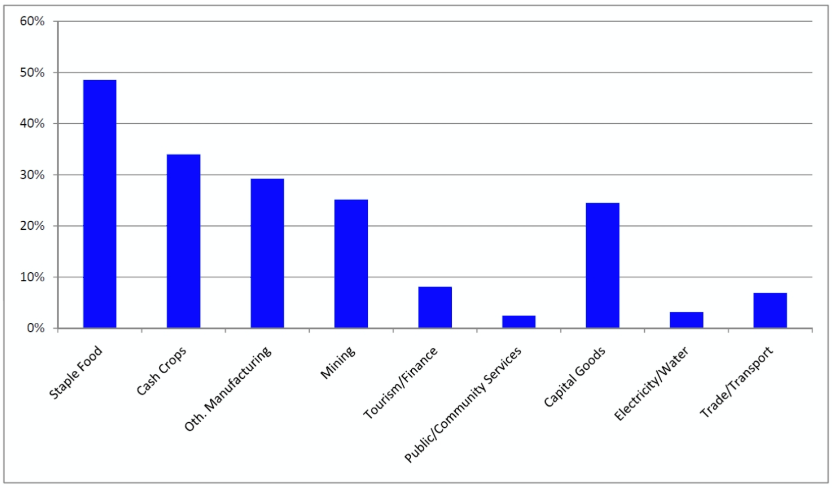


Table 3.1 summarizes the regression results for different specifications. m_{ag} represents the trade and transport margin in the agricultural sectors, which should be more sensitive to road quality compared to m_{all} which is the weighted average of the trade and transport margin over all sectors. All variables have been used in natural logarithms such that the results can be interpreted as elasticities. In addition, the use of logarithms significantly reduces the number of outliers which is important here given the rather small sample and the fact that there is a large difference in magnitude between the different variables ($GDPC$ has much higher absolute values than the other variables).

The regressions clearly show that an increased availability of roads and railroads significantly reduces the trade and transport margin. This effect is robust across different specifications. The sign remains negative in all estimations and the coefficient is insignificant in only one specification. These findings clearly confirm the theoretical considerations described above and support our way of modeling infrastructure. The relation is confirmed not only for the agricultural sector but also for the weighted transport expenditure of all sectors.[13]

[12] The inclusion of these countries does not change the qualitative results but removes the significance of most coefficients.
[13] The inclusion of additional or alternative controls like the HDI instead of GDP per capita or an

Table 3.1.: Results of cross-sectional OLS regressions

Spec. no	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$
# Obs.	53	53	53	53	45	45	45	45
ln(transp)	-0.16**	-0.18***	-0.19***	-0.12**	-0.14**	-0.16***	-0.04	-0.12**
ln(gdp)		-0.07	-0.05	-0.10		-0.07	-0.08	-0.10
ln(urban)			-0.08	-0.06			0.03	0.02
ln(pop)				-0.17***				-0.07
R^2	0.28	0.30	0.30	0.40	0.34	0.37	0.37	0.39
adj. R^2	0.27	0.27	0.25	0.35	0.33	0.34	0.32	0.33
F-test	20.1***	10.5***	6.9***	7.9***	22.2***	12.1***	7.9**	6.4***

*** significant at 1% level, ** significant at 5% level, * significant at 10% level

The elasticities between 0.04 and 0.18 seem to be rather small but this is due to the fact that the independent variable is *transport network density*. As the transport density lies between 0.007 and 2.667 in our sample, a 1% increase of this density is often a very small shock. For Zambia, for instance, a 1% increase in the density would require 87 km of additional roads or rail roads to be built and additional public investment of less than 0.01% of the GDP. This is far below the yearly public investment budget. In fact our results correspond quite well with those of Teravaninthorn & Raballand [2009] if we assume that an improvement of the quality of roads from "fair" to "good" approximately requires a doubling of the transport density. This would imply a 15% decrease in average transport costs which is consistent with our elasticities.

These results are promising and support the general idea of this paper. Nonetheless, it is desirable to have even more reliable estimations of the elasticity. Ideally, transport costs should include time and loss on the road. Unfortunately, the data for such an investigation is not available at a broad cross-sectional or panel level. It would be preferable to use "transport network capital" as an explanatory variable, which would be closer to the theory and the concept of public investment. However, this could not be used due to data limitations, measurement problems and problems of comparability across countries. Moreover, an extension of our sample by adding more countries would be desirable.

3.5. Simulations and results

3.5.1. Calibration

The CGE model is calibrated to a base year data set in order to provide a benchmark structure of the economy. The data used for this paper is a slightly idealized SAM for Zambia. Zambia represents a typical Sub-Sahara African country here. Its transport network density of 0.012 km of paved roads and railroad per km^2 of surface is among the

education index does not change the results qualitatively but provide results of lower reliability.

lowest in the world and only at less than 1% of the German transport density. The SAM has been aggregated to a rather high level of aggregation: nine sectors of production, two households, two types of labor and one type of capital. For simplicity, very small data entries have been removed from the data base and transfers between households, too. The different forms of indirect production taxes have been aggregated to only one. This aggregation reflects the methodological focus of this study. In this manner it is ensured that effects from an increased road density are clearly identifiable and not hidden in a very complex system of second and third round effects. Nonetheless, the data set is rich in terms of the information provided concerning households' home consumption as well as the trade and transport margins. The data contains sectoral information about distinct trade and transport margins for domestic supply, imported supply and exports. It also provides sectoral levels of home consumption per household type. Information of this type is needed for a consistent calibration of the model.[14]

The previously estimated infrastructure-elasticity of the trade and transport margin is reflected in the model in the input/output-relation of the road-sector which must be set exogenously. The CGE model has been calibrated to an elasticity of 0.15 but different levels have been implemented in robustness tests.

All other parameters for the calibration of the model are either calculated from the base year data (input coefficients, production function exponents, shares in consumption, tax rates, savings rates) or have been taken from the relevant literature (CET- and CES-elasticities in the Armington formulation).

3.5.2. Simulations

The CGE model described above has been used to run a series of simulations with increases in the transport density between 5% and 100%. This large range of shocks serves to investigate whether there might be a minimum amount of investment required to produce any effect and whether there exist decreasing returns to public investment. In addition, public investment levels differ significantly across countries and thus there is no obvious counterfactual at this stage of model development.

In order to provide a general idea of the dimension of the simulated shocks either projections about the infrastructure requirements of developing countries or past investment budgets of the respective states could be taken into account. As a point of reference one might consider the work by Fay & Yepes [2003] who calculated actual infrastructure investment needs for a large sample of countries for 2000-2010. They find that Sub-Saharan African countries should on average invest 5.5% of their GDP per year into infrastructure in general of which 2.8% in new investments and 2.7% in maintenance. Approximately 20% of these investments should be spent on roads.[15] Taking world average investment

[14] The original dataset is: Thurlow *et al.* [2005].

[15] Very roughly calculated this would mean annual road investments of 1% of the GDP, half of which

costs for new roads as in Fay & Yepes [2003] these investments would translate into an increase in the transport density between 60 and 200% in the Zambian case.[16]

These rough calculations serve to provide some idea of the dimensions. For this reason we simulate a wide range of shocks, keeping in mind that 5% is far below the requirements and 100% might be above the realistic increases in the stock of infrastructure. Nonetheless, it would clearly be possible to simulate any given amount of investment or any given length of additionally paved roads if concrete amounts of investment and prices for these are known. Note, a 100% in infrastructure density is comparable to the infrastructure shock of 2.5% of the GDP simulated by Adam & Bevan [2006]. Agenor *et al.* [2008] and Levy [2006] simulate substantially larger infrastructure shocks of 5% and 15% of the GDP respectively.

In addition to the range of possible magnitudes of the public investment programmes one can think of different assumptions about the distribution of welfare effects. We therefore run the simulations for three different scenarios. In general, welfare effects will be savings in terms of traveling time, capital in transportation and avoidance of goods loss. There is some empirical evidence for instance by Jacoby & Minten [2009] that these effects are higher for households which are located in remote regions. In our setup with only two household types (rural and urban) this would mean that only the rural households benefit directly from welfare gains. Alternatively, urban households might benefit as well with a greater diversity of goods supplied and a general lowering in transportation costs. Hence, we also include a scenario in which the welfare gains are assigned proportionally to all households. A third notion is the incorporation of the financing of an infrastructure project through increased taxes. In this scenario the government collects the welfare gains through some form of tax e.g. fuel taxes, road charges or motor vehicle taxes and uses the additional income to redeem the loans it took to finance the road and to provide more and better public services. As this last scenario is distribution-neutral and will mainly show the supply side effects it serves as a benchmark case in this study and is later compared with the other two cases.[17]

The size of the elasticity of transport costs with respect to the provision of roads has not been studied before. The only concrete number stems from our own estimation. As a robustness check we therefore run a series of simulations in which we keep the level of investment constant (at levels resulting to a 20% and 100% increase in the transport density) and increase the elasticity parameter. These results will also be briefly

would provide new roads and half of which should be spent on maintaining old roads. Taking Zambia as an example this would mean a transport network budget of about 65 billion Zambian Kwacha (ZK). The Zambian public capital investment in the base year amounted to about 1000 billion ZK. Assuming that on average 20% of investment programmes are dedicated to infrastructure investment this would mean an investment budget of 200 billion ZK.

[16]Note, this leaves aside increases in the quality through maintenance.

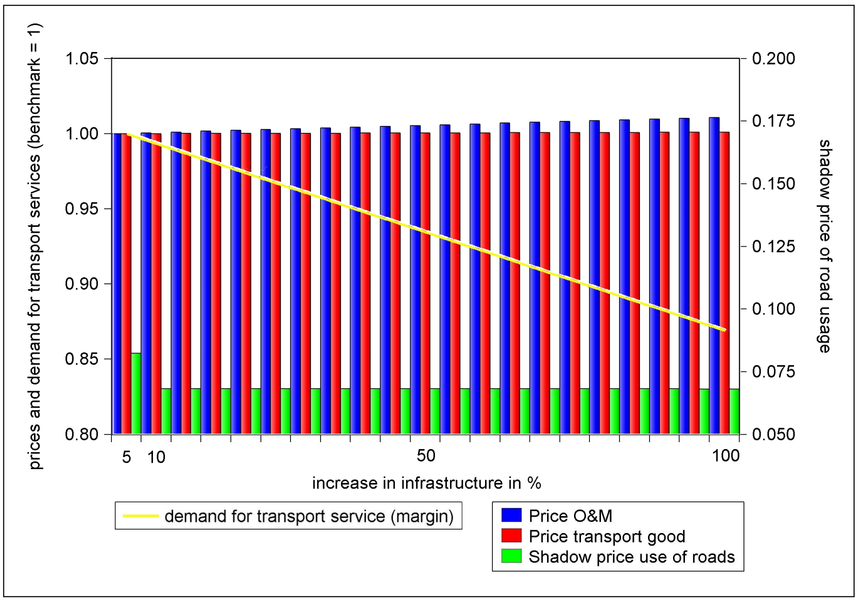
[17]Tax financing of infrastructure is rather unrealistic in most African countries due to underdeveloped tax systems, nonetheless, given the neutrality concerning distribution, we use this artificial scenario as a benchmark. A concrete policy analysis could include the financing of infrastructure explicitly.

summarized.

3.5.3. Results

The simulations show that with increasing availability of transport infrastructure, the demand for trade and transport services (and thus for capital and labor in transportation) decreases while the overall production and consumption increases. In the benchmark case where the government redistributes the welfare gains the increase in consumption is spread evenly across households.

Figure 3.7.: Transport sector results



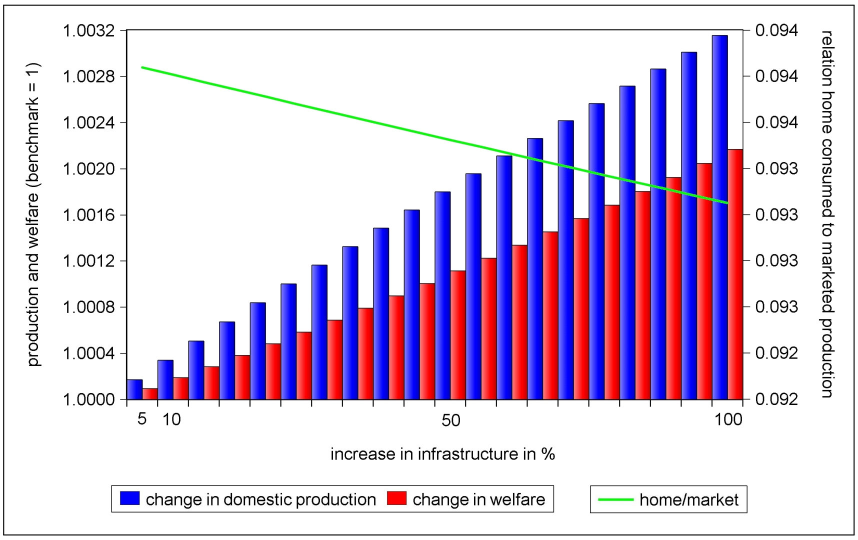
The demand for transport services clearly decreases with increasing availability of roads. Nevertheless, the price for transporting goods to markets remains constant. This is due to the fact that the overall demand for the transport aggregate will increase given the increase in production. The effects on production and consumption are shown in figure 3.8.

Domestic marketed production (indicated by the black line in figure 3.8) increases with increasing availability of "free" transport.[18] Capital and labor released in the transport sector may now be used in other sectors. Home consumption relative to total output is captured in the grey bars and is clearly decreasing on the aggregate level.

The increased production is mainly consumed domestically. The grey line represents

[18]The increase in domestic production by only about 0.25% seems to be a small reaction to an increase in infrastructure by 100%. However, a doubling of infrastructure would lead to an infrastructure density of 0.024 km per km^2 of surface which still is one of the lowest infrastructure densities in the world. Nonetheless, it would require to build about 7000 km of new roads and rail roads which would be an expensive project for the Zambian government. Zambian infrastructure is so far below the requirements that even doubling it would still have only small effects.

Figure 3.8.: Production, welfare and home consumption for different levels of infrastructure



the Hicks equivalent change in welfare which is the change in real consumption possibilities of private households measured in units of initial consumption. The gains from better transport thus translate indeed into a higher level of overall welfare. The aggregate use of factors of production in the other sectors except transport services increases compared to the base year.

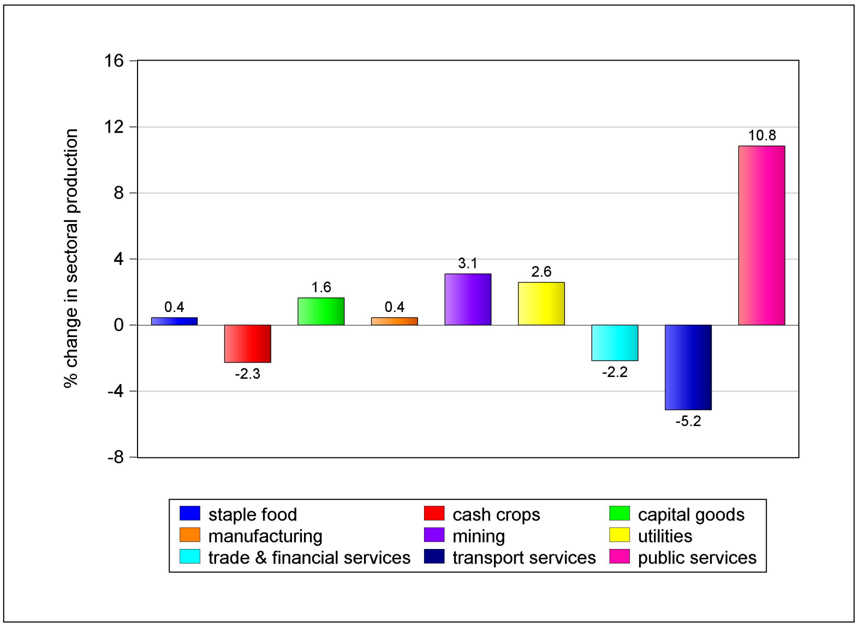
The additionally available factors are distributed very unevenly across sectors. The production of trade and transport services clearly drops. Correspondingly, we see a substantial increase in the production of public and community services. This effect has two sources: First, the additional roads need maintenance which creates a higher demand for public services. Second, the government uses a part of its higher income to provide a higher level of public services (apart from road maintenance).

As the different sectors have differing transport intensities[19] a shock on transport costs will have substantially different effects on the different sectors. Indeed we see in figure 3.9 that sectoral production in some sectors increases substantially whereas other sectors are nearly unaffected. Namely public and community serves directly benefit from increased demand due to road maintenance and from additional tax income. But also the mining sector (MIN), the utilities sector (EAW) and the capital goods sector (INV) benefit from lower transportation costs and additional labour supply. The staple food (STF) and other manunfacturing (MAN) are nearly unaffected whereas agricultural cash crops production (CCR) and tourism and financial services (TFI) face shrinking production.

The mining and capital goods benefit because they are caracterized by a combination of high transport intensity and high capital share in value added. The prices both for

[19]See figure 5.1 for a summary of transport margins in the different sectors.

Figure 3.9.: Sectoral real production at an infrastructure level of 150%



transport and capital decrease and thus these sectors benefit twice. Public and community services benefit from a positive demand shock. Electricity and water are also produced capital intensive and thus profit from decreasing costs. Relative wages on the other hand rise and thus the labor intensive sectors staple food and cash crops do not benefit. Transport services face a negative demand shock as well as financial services which are the main intermediate demanded in transport.

In figure 3.10 we see that at the sectoral level home consumed production evolves in correspondence to marketed production.[20] This implies that in the sectors where home consumption is possible, only the agricultural sectors and food processing, the share of home consumption is more or less kept constant in contrast to the theoretical predictions. Nonetheless, as the production in other sectors increases significantly, the share of aggregate home consumption in aggregate consumption decreases correspondingly. This apparent paradox can be explained as follows: Given the fact that home produced agricultural products are by assumption perfect substitutes for marketed agricultural products, home consumption is always preferable to marketed goods in agricultural sectors as long as there exist positive transport costs inducing a higher relative price for marketed goods. Nevertheless, the welfare gains from better infrastructure allow the households to increase their consumption not only of home consumed goods but also of other, market-only goods. Thus, we see a change in the composition of the aggregate consumption bundles of both households in favor of marketed goods. We do not observe a substitution effect between home consumed and market goods within one sector but between sectors.

[20]Note that home consumption is only possible in agricultural sectors and very basic manufacturing.

Figure 3.10.: Sectoral effects at an infrastructure level of 150%

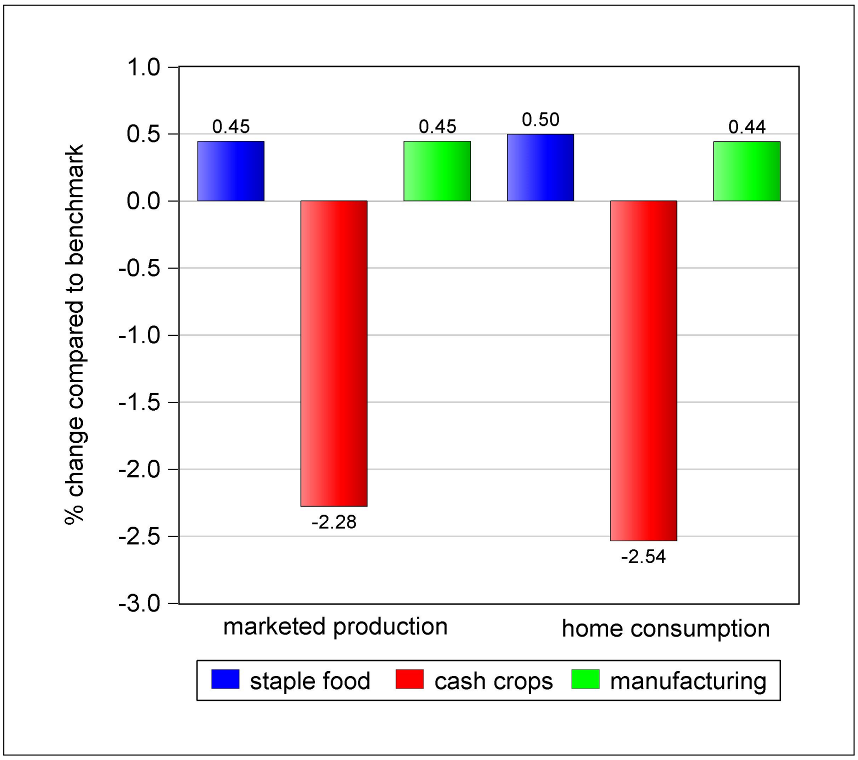
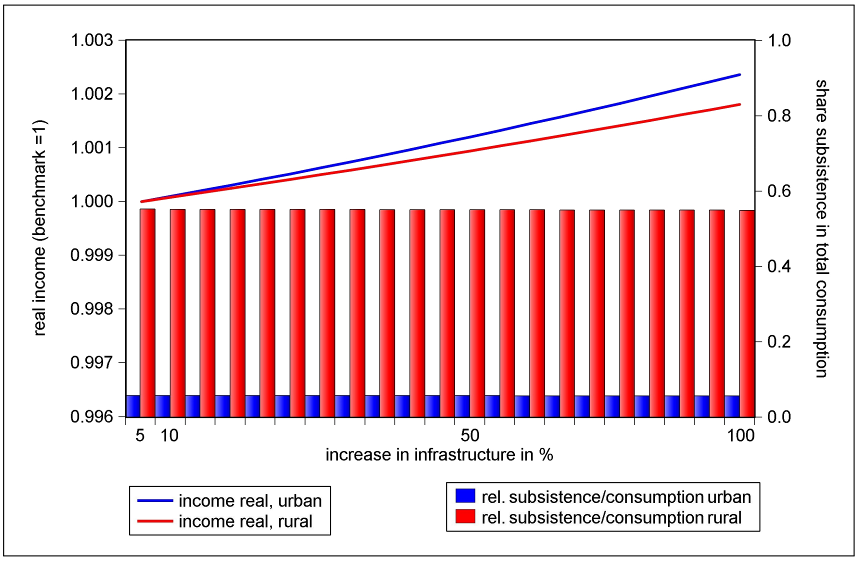


Figure 3.11.: Income and consumption



As the government collects the welfare gains in form of an endogenous tax on infrastructure in this baseline scenario, the investment programme is (nearly) distribution neutral.

Figure 3.11 illustrates the aforementioned phenomenon that even though the quantity of produced goods in the category of subsistence agriculture increases parallel to total output in agriculture, home consumption has a constant or slightly declining importance in the consumption bundles of both households.

3.5.4. Alternative specifications of welfare effects

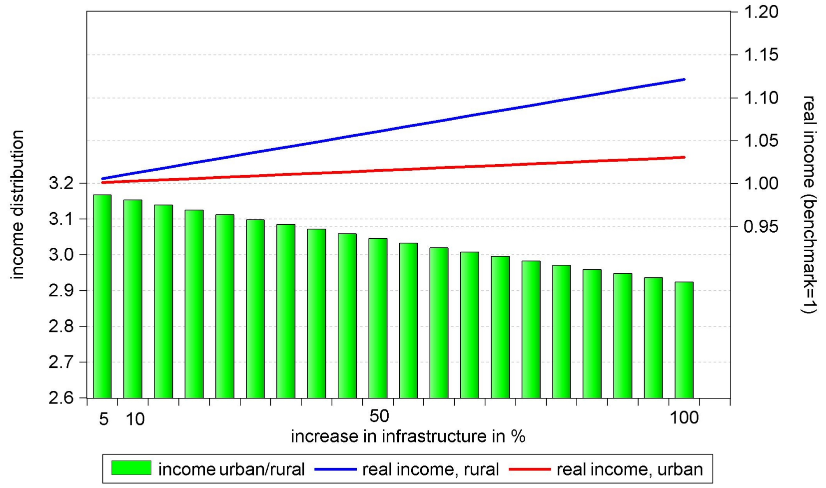
As described above welfare gains might either be assumed to favor the rural households, to be equally spread across all households or to be redistributed through public services. These three scenarios are simulated and compared.

At the aggregate level, the welfare effect depends significantly on the assumption that households benefit directly from better transport infrastructure but not on the assumption which household receives the welfare gains directly. Figures 3.13 and 3.14 in the appendix show that the aggregate welfare effect is much higher if the welfare effects are completely assigned to private households. However whether all households benefit or only rural households does not have an influence on the aggregate effect on welfare, production and home consumption. Nevertheless, this assumption obviously has an influence on distribution.

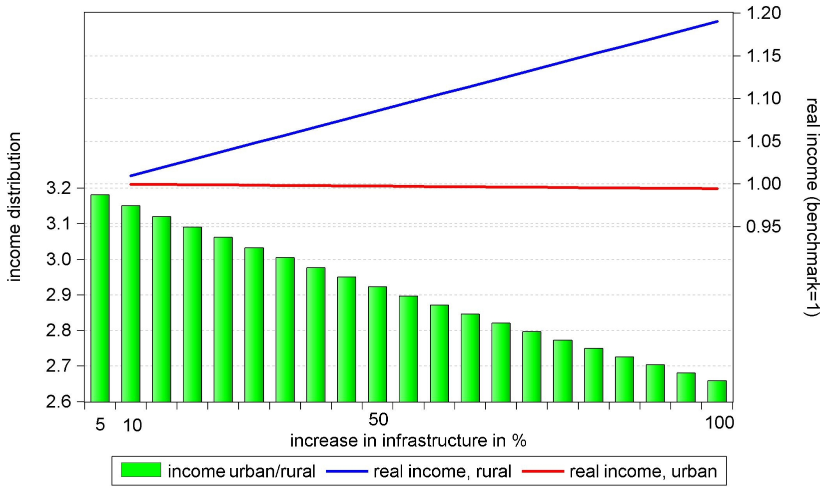
Even if the welfare gains are distributed to all households in accordance to their share in the population, we see a clearly poverty-reducing distributional effect, as the rural households represent a higher share of the population. Figures 3.12(a) and 3.12(b) show the effect of infrastructure on income and income distribution for the two different assupmtion sets.

Compared to the neutral scenario we see a more pronounced drop in the aggregate relation of home consumption to marketed production because private households demand more transport intensive goods compared to the government. Thus, the transport cost effect has a higher impact on the composition of consumption bundles if private households dispose of the additionally available resources. The effect on home consumption at the household level is shown in figure 3.15 in the appendix.

Figure 3.12.: Effects on income distribution with different assumption sets



(a) All households benefit directly



(b) Only rural households benefit directly

3.5.5. Robustness

It is important to mention that the quantitative dimension of the results depends on a number of assumptions. Most importantly, the value of the additional infrastructure capital has been calculated on the basis of world average public investment prices. This is only a very rough approximation for the purpose of illustration of the model's capabilities. This assumption does not affect the relative results but the overall magnitude of the effects.

In contrast the relative results and the proper working of the model might be sensitive with respect to the assumed elasticity of the trade and transport margin. As a robustness check we keep the level of investment constant at 20% and 100% increase in the transport density and change the elasticity parameter between 0.0005 and 0.01. The results are only affected in their magnitude but show a linear relationship to the elasticity parameter. The model compilation and solution is robust with respect to changes in the elasticity parameter.

3.6. Policy implications and conclusion

This paper shows that even though there seems to be a consensus about the positive effects from better roads on development which is reflected in a number of investment programs, the evidence in the development economics literature is mixed and far from being complete. Most importantly, there is often no explicit accounting for different forms of infrastructure. Theoretical contributions often mention a transport cost reducing effect from roads. Nonetheless, concrete quantitative results are scarce and unreliable. In addition, the theoretical reflections in the literature have not been translated into appropriate models for policy analysis.

This paper contributes to the existing literature on transport infrastructure in several ways: We show how the verbal theoretical considerations on the direct and indirect effects from better roads can be translated into a general equilibrium setup. We develop a small stylized model of transport infrastructure and apply the same methodology in a realistic CGE thereafter. In addition to this contribution in the field of CGE modeling we present empirical evidence for a clear and significant negative relationship between transport networks and trade and transport margins. We measure transport costs as the share of spending on trade and transport inputs in total sectoral output.

Simulations with the CGE model confirm that with increasing availability of roads the demand for labor and capital for transport declines. These factors move to the other sectors to produce a higher aggregate output. Welfare, measured as real consumption increases on average and at the disaggregate level for all households. The composition of the new consumption bundle and hence the reaction of subsistence agriculture depends on the assumption which households benefit directly from shorter traveling times and less goods lost on the road. As rural households spend a large share of their income on food the higher the rural gains the higher the share of agriculture in additional production and hence the higher the share of subsistence agriculture, too. Especially if infrastructure programs are in favor of rural areas, the welfare effect clearly transcends the output effect.

The empirical and simulation results show that infrastructure investment programs are a well-suited instrument to support the development of a country as increased infrastructure has positive effects on production and welfare. However, infrastructure projects are extremely costly and the empirical literature emphasizes that efficient planning of such projects is of major importance. We clearly confirm this in our model simulations. Infrastructure affects the production sectors differently depending on their transport intensity and their factor input requirements. Especially manufacturing and capital-intensive activities benefit while agricultural sectors are less favored given the relative increase in wages. Hence, a pro-poor investment strategy especially in agricultural economies should target rural areas specifically. We do not confirm that a substantially higher proportion of agricultural goods is marketed as transport costs are still above zero but nonetheless the production and consumption of market-only consumption goods increases broadening the consumption possibilities. Another important factor to bear in mind is the increased demand for public and community services due to higher O&M spending. These require that at least part of the welfare gain from new roads is collected through taxes and used for maintenance.

Even though the simulation results correspond to the theoretical predictions, the magnitude of the effects is relatively small compared with the high investment costs. This is partly because the initial road density is so low that even doubling the availability leaves the country with a highly insufficient network. In addition, our robustness checks show that altering the elasticity parameter changes the magnitude of the effects. The direct effect from increased investment demand has been neglected here as well as the possible dynamic effects induced by the structural changes shown here. A promising way of developing the model further would be to transform it into a fully dynamic model. However, it requires reliable estimations not only of the road-elasticity of the transport margin but also on investment costs and depreciation as well as maintenance costs on the national level.

The model presented here can be very useful in evaluating concrete infrastructure investment projects and programs. It has been applied to a highly aggregated dataset but could easily be used with very detailed data as well and thus provide important insights into sectoral and distributional effects from better transport networks, too.

B. Appendix

B.1. Model specification

Table 3.2.: Armington elasticities

sector	Elasticity of Substitution	Elasticity of Transformation
Staple Food	2.0	0.75
Cash Crops	1.5	4.0
Manufacturing	1.5	1.25
Mining	1.5	4.0
Tourism&Finance	0.2	0.2
Publ. Services	0.2	0.2
Capital Goods	0.5	0.5
Utilities	1.0	1.0
Trade&Transport	2.0	2.0

B.2. Results

Complete result listing - Redistribution of welfare gains through government

Table 3.3.: Infrastructure and transport demand and prices

% increase in infrastructure	demand for transport service (margin)	Price transport good	Price O&M	Price use of roads
0	1.0000	1.0000	1.0000	0.0824
5	0.9935	1.0000	1.0005	0.0683
10	0.9869	1.0001	1.0011	0.0682
15	0.9804	1.0001	1.0016	0.0682
20	0.9739	1.0002	1.0021	0.0682
25	0.9673	1.0002	1.0027	0.0682
30	0.9608	1.0003	1.0032	0.0682
35	0.9543	1.0003	1.0037	0.0682
40	0.9477	1.0004	1.0043	0.0682
45	0.9412	1.0004	1.0048	0.0682
50	0.9347	1.0004	1.0054	0.0682
55	0.9281	1.0005	1.0059	0.0682
60	0.9216	1.0005	1.0064	0.0682
65	0.9151	1.0006	1.0070	0.0682
70	0.9085	1.0006	1.0075	0.0682
75	0.9020	1.0007	1.0081	0.0682
80	0.8955	1.0008	1.0086	0.0682
85	0.8889	1.0008	1.0091	0.0681
90	0.8824	1.0009	1.0097	0.0681
95	0.8759	1.0009	1.0102	0.0681
100	0.8693	1.0010	1.0108	0.0681

Table 3.4.: Production, welfare and home consumption

% increase in infrastructure	Hicks equivalent welfare	change in welfare	Domestic production	change in domestic production	Home consumption	Home/ Marketed production
0	10798		26170		2456	0.0938
5	10799	1.0001	26174	1.0002	2455	0.0938
10	10800	1.0002	26179	1.0003	2455	0.0938
15	10801	1.0003	26183	1.0005	2454	0.0937
20	10802	1.0004	26188	1.0007	2453	0.0937
25	10803	1.0005	26192	1.0008	2453	0.0936
30	10804	1.0006	26196	1.0010	2452	0.0936
35	10805	1.0007	26200	1.0012	2451	0.0936
40	10806	1.0008	26205	1.0013	2451	0.0935
45	10808	1.0009	26209	1.0015	2450	0.0935
50	10809	1.0010	26213	1.0016	2449	0.0934
55	10810	1.0011	26217	1.0018	2449	0.0934
60	10811	1.0012	26221	1.0020	2448	0.0934
65	10812	1.0013	26225	1.0021	2448	0.0933
70	10814	1.0015	26229	1.0023	2447	0.0933
75	10815	1.0016	26233	1.0024	2446	0.0933
80	10816	1.0017	26237	1.0026	2446	0.0932
85	10817	1.0018	26241	1.0027	2445	0.0932
90	10819	1.0019	26245	1.0029	2444	0.0931
95	10820	1.0020	26249	1.0030	2444	0.0931
100	10821	1.0022	26253	1.0032	2443	0.0931

Table 3.5.: Factor prices

% increase in infrastructure	wage unskilled	wage skilled	land rent	capital rent
0	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0008	0.9999	0.9999
10	1.0000	1.0015	0.9998	0.9998
15	1.0001	1.0023	0.9997	0.9997
20	1.0001	1.0030	0.9995	0.9997
25	1.0001	1.0038	0.9994	0.9996
30	1.0001	1.0045	0.9993	0.9995
35	1.0001	1.0053	0.9992	0.9994
40	1.0002	1.0061	0.9990	0.9993
45	1.0002	1.0068	0.9989	0.9992
50	1.0002	1.0076	0.9988	0.9992
55	1.0002	1.0083	0.9987	0.9991
60	1.0002	1.0091	0.9986	0.9990
65	1.0002	1.0098	0.9984	0.9989
70	1.0003	1.0106	0.9983	0.9988
75	1.0003	1.0114	0.9982	0.9987
80	1.0003	1.0121	0.9981	0.9986
85	1.0003	1.0129	0.9980	0.9986
90	1.0003	1.0136	0.9978	0.9985
95	1.0004	1.0144	0.9977	0.9984
100	1.0004	1.0152	0.9976	0.9983

Table 3.6.: Sectoral production

% increase in infrastructure	Staple Food	Cash Crops	Manufacturing	Mining	Trade and financial services	Public and community services	Investment goods	Utilities	Transport services
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0005	0.9977	1.0004	1.0031	0.9978	1.0109	1.0016	1.0026	0.9948
10	1.0009	0.9954	1.0009	1.0062	0.9957	1.0218	1.0033	1.0052	0.9897
15	1.0014	0.9931	1.0013	1.0093	0.9935	1.0326	1.0049	1.0077	0.9845
20	1.0018	0.9908	1.0018	1.0124	0.9913	1.0435	1.0066	1.0103	0.9794
25	1.0022	0.9885	1.0022	1.0155	0.9892	1.0543	1.0082	1.0129	0.9742
30	1.0027	0.9863	1.0027	1.0186	0.9870	1.0651	1.0098	1.0155	0.9691
35	1.0031	0.9840	1.0031	1.0217	0.9849	1.0759	1.0115	1.0180	0.9639
40	1.0036	0.9817	1.0036	1.0248	0.9827	1.0867	1.0131	1.0206	0.9588
45	1.0040	0.9795	1.0040	1.0279	0.9805	1.0975	1.0147	1.0232	0.9536
50	1.0045	0.9772	1.0045	1.0310	0.9783	1.1082	1.0164	1.0258	0.9485
55	1.0049	0.9750	1.0049	1.0341	0.9762	1.1190	1.0180	1.0283	0.9433
60	1.0053	0.9728	1.0054	1.0372	0.9740	1.1297	1.0196	1.0309	0.9382
65	1.0058	0.9705	1.0058	1.0403	0.9718	1.1404	1.0212	1.0335	0.9330
70	1.0062	0.9683	1.0063	1.0434	0.9697	1.1512	1.0228	1.0361	0.9279
75	1.0066	0.9661	1.0067	1.0466	0.9675	1.1618	1.0245	1.0386	0.9227
80	1.0071	0.9639	1.0072	1.0497	0.9653	1.1725	1.0261	1.0412	0.9176
85	1.0075	0.9617	1.0076	1.0528	0.9632	1.1832	1.0277	1.0438	0.9124
90	1.0079	0.9595	1.0081	1.0559	0.9610	1.1938	1.0293	1.0464	0.9073
95	1.0084	0.9573	1.0085	1.0591	0.9588	1.2045	1.0309	1.0489	0.9021
100	1.0088	0.9552	1.0090	1.0622	0.9566	1.2151	1.0325	1.0515	0.8970

Table 3.7.: Sectoral home consumption

% increase in infrastructure	Staple Food	Cash Crops	Manufacturing
5	1.0005	0.9974	1.0004
10	1.001	0.9949	1.0009
15	1.002	0.9923	1.0013
20	1.0020	0.9898	1.0018
25	1.0025	0.9872	1.0022
30	1.0030	0.9847	1.0027
35	1.0035	0.9822	1.0031
40	1.0040	0.9797	1.0035
45	1.0045	0.9771	1.0040
50	1.0050	0.9746	1.0044
55	1.0055	0.9721	1.0049
60	1.0060	0.9697	1.0053
65	1.0064	0.9672	1.0058
70	1.0069	0.9647	1.0062
75	1.0074	0.9623	1.0067
80	1.0078	0.9598	1.0071
85	1.0083	0.9574	1.0076
90	1.0088	0.9549	1.0080
95	1.0092	0.9525	1.0085
100	1.0097	0.9501	1.0089

Table 3.8.: Income distribution

% increase in infrastructure	income real, rural	income real, urban	income urban/ rural	rel. subsistence/ consumption rural	rel. subsistence/ consumption urban
0	1.0000	1.0000	3.1820	0.5519	0.0570
5	1.0001	1.0001	3.1820	0.5518	0.0569
10	1.0002	1.0002	3.1821	0.5516	0.0569
15	1.0002	1.0003	3.1822	0.5515	0.0568
20	1.0003	1.0004	3.1822	0.5514	0.0568
25	1.0004	1.0005	3.1823	0.5512	0.0567
30	1.0005	1.0006	3.1824	0.5511	0.0567
35	1.0006	1.0007	3.1825	0.5509	0.0566
40	1.0007	1.0009	3.1825	0.5508	0.0566
45	1.0008	1.0010	3.1826	0.5506	0.0565
50	1.0009	1.0011	3.1827	0.5505	0.0565
55	1.0009	1.0012	3.1828	0.5504	0.0565
60	1.0010	1.0013	3.1829	0.5502	0.0564
65	1.0011	1.0014	3.1830	0.5501	0.0564
70	1.0012	1.0016	3.1831	0.5499	0.0563
75	1.0013	1.0017	3.1832	0.5498	0.0563
80	1.0014	1.0018	3.1833	0.5496	0.0562
85	1.0015	1.0020	3.1834	0.5495	0.0562
90	1.0016	1.0021	3.1835	0.5493	0.0561
95	1.0017	1.0022	3.1836	0.5492	0.0561
100	1.0018	1.0024	3.1837	0.5490	0.0560

Selected figures - Alternative welfare allocation scenarios

Figure 3.13.: Production, welfare and home consumption - All households benefit

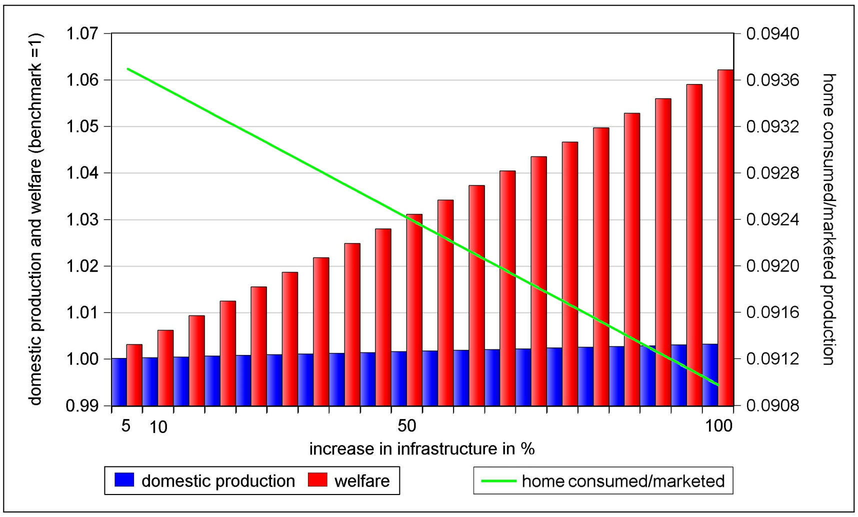


Figure 3.14.: Production, welfare and home consumption - Only rural gains

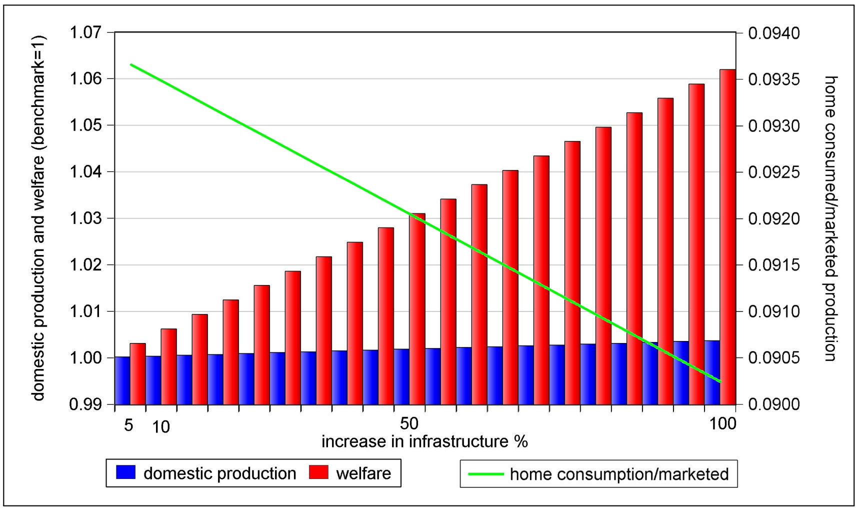
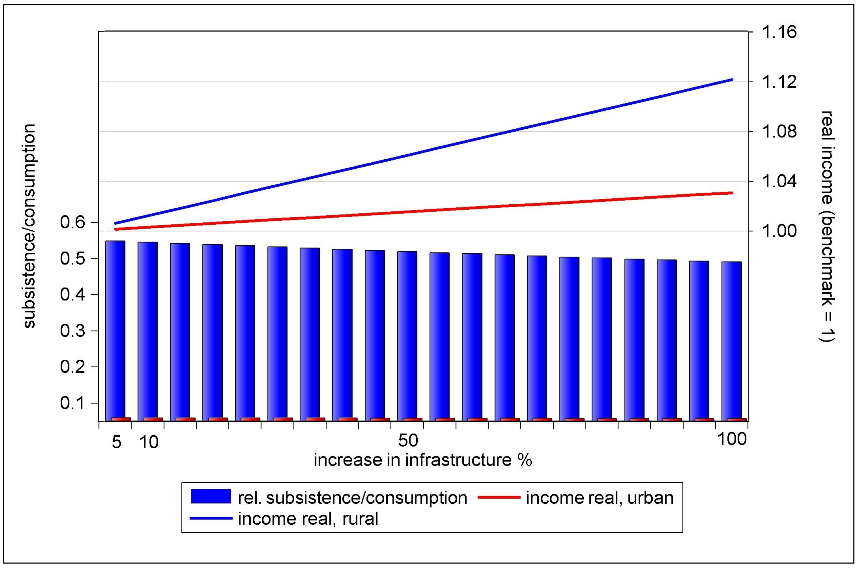


Figure 3.15.: Income distribution - All households benefit



B.3. Model code listing

**Model code documentation
not included in electronic version.**

**Please contact the author
for a copy of the model code.**

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4. One model fits all? Determinants of transport costs across sectors and country groups

Abstract

We show with pooled OLS estimations based on transport margins from international social accounting data that investments in improved road infrastructure have the potential to significantly reduce transport costs. However, this result can only be clearly confirmed for industrial countries and is of primary importance for the production and transportation of agricultural goods. For developing and transition countries, in contrast, we find other determinants such as weather conditions to be more important in determining transport costs. A key variable, especially in these countries, is corruption. Very high corruption has the potential to prevent positive effects from roads on transport costs or to even reverse them. This paper contributes to the literature on infrastructure investment by introducing and applying an internationally comparable measure of transport costs which can be calculated for a large number of countries. We conclude that investment in transport infrastructure can have substantial positive effects especially on agricultural production and the efficient marketing of agricultural products but only if specific additional conditions are in place.

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> " It costs more to transport a vehicle from Abidjan to Addis Ababa than shipping the same vehicle from Abidjan to Japan."
> *Naude & Mathee [2007]*

4.1. Introduction

Investment in infrastructure is often seen as a promising path for growth and development. Based on the experiences with large infrastructure investments in industrial countries, like e.g. the first transcontinental railroad in the U.S. finished in 1869, infrastructure projects are widely considered to induce large growth effects. However, the magnitude of the estimated effect differs quite substantially.

Classic studies in the field of economic history like Jenks [1944] or Fishlow [1965] for the United States and Fremdling [1977] for Germany argue that the connection of markets through railways had a massive influence on the industrialisation of the respective countries. Comparable studies also exist for the initial construction of motorways in industrial countries. In modern industrial economies infrastructure networks are still seen as important prerequisites for regional development. This is for example reflected in the large scale infrastructure programmes after German reunification and also in the inclusion of infrastructure into the aims of the Lisbon strategy:[1]

> Establishing an efficient trans-European transport network (TEN-T) is a key element in the relaunched Lisbon strategy for competitiveness and employment in Europe. If Europe is to fulfil its economic and social potential, it is essential to build the missing links and remove the bottlenecks in our transport infrastructure, as well as to ensure the sustainability of our transport networks into the future. (European Commission)

The assumption that infrastructure reduces transport costs is also included in many gravity models in international trade. Infrastructure is included as an explanatory variable in some of these models which implicitly assumes that there is an influence of infrastructure on trade costs. [See e.g. Portugal-Perez & Wilson, 2008]

Policy initiatives such as the WTO's *Aid for Trade* program or the World Bank's *Infrastructure Action Plan* emphasize the importance of infrastructure for developing countries. This political emphasis on infrastructure reflects the widespread belief that the observed positive effects from infrastructure in developed countries apply to developing countries as well.

The literature usually argues that improvements in the road network reduce transport costs and transport times. The studies on Americas railways distinguish three types of effects from infrastructure improvements: the direct effect on transport costs which is

[1] Source: European commission `http://ec.europa.eu/transport/infrastructure/index_en.htm`

argued to reduce transaction costs and thus increase the volume and number of transactions, the *backward linkage* through increased demand for resources and factors needed for infrastructure construction and the *forward linkage* effect which summarizes the induced additional economic activities due to the presence of infrastructure. The importance of the direct cost reducing effect (which is also a prerequisite for *forward linkage* effects) has been stressed in many subsequent studies.

Reduced transport costs are e.g. mentioned as important results from infrastructure investment in developing countries in Escobal & Ponce [2002] and Teravaninthorn & Raballand [2009]. However, even for industrial countries, concrete estimations for the travel cost reduction from better roads are scarce. This is partly due to the fact that time series based studies for distinct countries cannot provide internationally applicable results. There are a number of studies in the international trade literature that quantify the tariff equivalent costs of poor roads on international trade but these cannot provide any insight concerning *intranational* transport and often focus on industrial countries alone [See e.g. Yeats, 1980; Limao & Venables, 2001; Portugal-Perez & Wilson, 2008].[2] Evidence on the effects of better roads in developing countries is mixed.[3] Existing country studies use substantially differing approaches to measure transport costs and hence it is difficult to conclude whether the determinants of transport costs are the same for developing and developed countries and even within these groups.

This paper contributes to the literature by developing and applying an internationally comparable measure of transport costs and estimating the effect of the length of transport ways on this measure across countries. Pooled estimations of the influence of transport network density on the transport margin show that better transport networks reduce transport costs. The effect is stronger for agricultural sectors compared to a weighted measure for all sectors. The observed effect from infrastructure on transport costs differs substantially across country groups. It cannot be confirmed unconditionally for developing and transition countries. In their case, other determinants such as weather conditions have a strong influence on transport costs as well. Most importantly, in low and middle income countries the effectiveness of road infrastructure strongly depends on the level of corruption. In highly corrupt countries the effect might be reversed and a higher level of infrastructure comes along with higher transport costs.

4.2. Literature and theoretical background

The literature on the effects from infrastructure investments states that improving the length and quality of roads and railroads would lead to higher output and lower poverty. The reasoning behind this is a combination of different positive effects. Roads in general

[2] The application of a comparable approach on intranational transport costs would require very detailed data.
[3] See Estache [2006] for a comprensive survey of the literature.

and paved roads in particular improve the connection between producers, markets and consumers. Enhancements of the roads and railroads of a country should hence lead to a more efficient allocation of goods and services.

Most macroeconomic studies on the effects of infrastructure follow the so-called production function approach based on Aschauer [1989] who applied the method to U.S. time series data. These studies estimate a national production function where GDP or growth depend not only on labour, capital and technology but also on public capital. Public capital is usually measured using the perpetual inventory method, i.e. aggregating past investment flows. This approach has been applied to developed and developing countries, to time-series, cross-section and panel data and there seems to be a consensus on the positive effect from public capital on output even though the magnitude of this effect is disputed. [See e.g. Hulten, 1996; Ram, 1996]. Hulten [1996] finds that the effect of public capital on growth is much lower if the sample comprises developing countries. He argues that this is due to less efficient planning and use in these countries. Also Aschauer [2000] states that it might be crucial whether existing infrastructure is used efficiently. Still, the methodology is only capable to investigate the effect of public capital as an entity instead of the effects of better transport networks in particular. This caveat is mentioned e.g. by Calderon & Serven [2008].

In addition to the considerable macroeconomic literature there exists a variety of country and case studies evaluating specific projects or programs. Examples for industrial countries are: Holl [2007]; Linneker & Spence [1996] and Vesper & Zwiener [1991]. Recent examples for developing countries are Olsson [2009] who analyses the Philippines, Escobal & Ponce [2002] who compare three African countries, Fan *et al.* [1999] for India or Fan [2008] for Uganda. For all of these countries it has been found that especially rural roads provide an instrument to reduce rural poverty and promote growth but only Olsson [2009] and Escobal & Ponce [2002] try to establish a more concrete chain of effects that explains the overall positive influence of roads. While Olsson [2009] offers theoretical reflections on this aspect, Escobal & Ponce [2002] estimate the effect of the road status on travel times and do not find a robust effect across the three countries in their sample.

Olsson [2009] argues that the positive aggregate effect of better and longer roads is based on an improved cost efficiency in transporting goods to markets. The lower transport costs are explained by shorter travel times combined with less loss on the road, direct market access even for small scale producers, reduced information asymmetries and quicker adaption to changes in supply and demand. In addition, Olsson [2009] expects that the economy undergoes structural changes as technologies spread more easily across the country.

While there exists strong empirical support for the general idea that improved roads lead to higher production and welfare, there is only a very limited number of studies that directly investigate the infrastructure - transport cost link. The link has been investigated for large past infrastructure projects in distinct countries like the U.S. railways or the Eastern German motorways but to our knowledge an international comparison of the transport cost effects of infrastructure investment is still due. This might be mainly due to the fact that data on transport costs across a large number of different countries is not available especially not for developing and transition countries.

The recent literature is rather vague about the exactly quantified relation between increased expenditure on infrastructure and the effect on transport costs. For developing countries there exist only very few studies. Escobal & Ponce [2002] and Teravaninthorn & Raballand [2009] focus on developing countries and especially on Africa. They apply a completely different methodology compared to most studies for industrial countries. In a case study of several international transport corridors in Africa Teravaninthorn & Raballand [2009] find that an improvement of the roads from "fair" to "good" reduces the transport cost by approximately 15%. Other concrete cross-country estimations that include intranational transport costs and not only international transport costs do not exist to our knowledge.

The measures for transport costs used in the different country and regional studies referenced above are very heterogeneous. Some rely on vehicle operation costs, others use freight rates or travel times. Hence, it is difficult to obtain a general result from comparing such country studies. However, it seems important to know whether the positive impact of infrastructure projects in industrial countries could possibly be replicated in developing countries. Summarizing the recent literature on infrastructure in developing countries Estache [2006] concludes that "the knowledge gap is not a small one".

4.3. Econometric design

4.3.1. Specification

Against this background this paper attempts to quantify the effect from better and longer roads on transport costs directly and investigates whether there exist systematic differences between industrial countries and developing and transition countries.

As an internationally comparable measure of transport costs we will use the transport margin (m). We calculate this margin as the sectoral spending on transportation relative to overall sectoral production costs and aggregate this over comparable sectors.

$$m_{i,s} = \frac{\text{transport related production costs in sector } s \text{ in country } i}{\text{total production cost in sector } s \text{ in country } i} \tag{4.1}$$

The transport margin thus comprises all elements of transport costs that have been reported as spending on road, air and water transportation, transportation related services and maintenance of transport vehicles. It indirectly covers wages paid to the labor and capital involved in transportation. The measure is not able to account for indirect costs of long transport ways such as the loss of perishable goods or the foregone profit due to the time spent on the road that could not be used productively (if not comprised in labor cost in transportation). As we calculate the cost measure relative to total sectoral cost we consider it highly comparable across countries even if production technologies differ substantially.

Information on sectoral spending on transportation can be obtained from social accounting data. Social Accounting Matrices (SAMs) are available for a large number of countries and for several years and provide detailed sectoral information on the demand for transport services.[4] This allows to build a dataset on international transport spending. The underlying SAMs differ in their level of disaggregation but can be aggregated to a comparable structure.

In a pooled estimation for 64 countries from all over the world and three periods we investigate the effect of transport density on these transport margins. This is a straightforward way to test the aforementioned theoretical reflections.

We estimate the following equation for each s separately:

$$ln(m_{i,s}) = \alpha + \beta\, ln(transnet_i) + \gamma\, controls_i + \delta\, dummies_i + u_i \tag{4.2}$$

As the dependent variable we use sectoral spending on transport services in country i relative to sectoral output in country i, i.e. the transport margin (m_i). We calculate this weighted margin from input-output data both only for agricultural sectors ($s = ag$) and over all sectors ($s = all$), we use sectoral output as weights.

Our main independent variable of interest is the road network density ($transnet_i$) measured here as the length of paved roads[5] in km per surface in km^2. We expect that higher transport network densities are associated with lower transport margins. In addition, we expect this effect to be stronger in agricultural sectors.

Several other variables should have an impact on transport costs. The GDP per capita ($gdpc_i$) as a proxy for the development of the economy but also for the overall transport demand is included as explanatory variable. One would expect that with higher overall transport demand, costs should decrease due to economies of scale. In contrast, if the level of technology is very low, an increasing GDP could also induce higher transport costs if transport is a very scarce service. This ambiguous ex ante expectation concerning the influence of $gdpc$ on transport costs might lead to a non-linear influence. We

[4] The results found with this measure might also be useful in the specification of SAM-based CGE models such as Jensen [2009].

[5] As an alternative measure for transport infrastructure we use paved roads and railroads taken together. This does not have a substantial impact on the results.

therefore test for non-linearity in GDP by including $gdpc^2$.

In addition, we control for the degree of urbanization ($urban_i$) as a measure of dispersion of the market participants. Intuition suggests a negative coefficient for urbanization over all sectors. A higher degree of urbanization implies shorter transport ways and thus lower transport margins. However, the opposite is true in agricultural sectors: If the major part of the population lives in towns, food has to be carried long distances from the production site to the consumers.

Moreover, we include the population density ($popdens_i$), measured as persons per km^2. On the one hand a higher population would mean higher transport requirements for transport of persons and thus imply a positive coefficient. On the other hand a smaller population might be spread across wide surfaces and thus need more transport which also induces higher transport costs and thus a negative coefficient for population density.

Climate conditions have a strong influence on both, the status of present roads and the possibility to use them. For this reason we include two climate variables: a temperature index and the yearly precipitation. The temperature index is calculated by adding up the squared maximum and minimum temperatures in degree Celsius for the respective year. Precipitation is measured in total mm per m^2 per year.

As we will focus part of our investigation on transport costs in agricultural sectors we include the fraction of land dedicated to agricultural use ($agrland_i$) in these estimations. A higher share of agricultural land is expected to increase the efficiency of transport in these sectors and thus decrease agricultural transport costs.[6]

Some studies on public investment argue that the efficiency of the use of public capital is very important and that part of public investment is never used productively due to corruptive elites. [See Hulten, 1996; Aschauer, 2000] For this reason we include *transparency international*'s *perceived corruption* index as an explanatory variable in some estimations. The index is defined between 0 and 10 where low values of the index are associated with very high levels of corruption.

As the sample comprises countries from all over the world, we include sets of dummy variables to control for structural differences between country groups. We alternatively include dummies for income groups, for geographical regions and for OECD member status.

We perform estimations both for the margin in agricultural sectors only and for the

[6]We tried to include the number of motor vehicles per 1000 persons as a proxy for transport technology. However, this measure is only available for a very limited number of periods and countries and thus the results are not reliable. The results are shown in table 4.11 in the appendix.

weighted margin aggregated over all sectors. All estimations use pooled data and OLS with hetero-scedasticity-corrected standard errors (White procedure). Given the frequent and systematic missings in our panel data set a fixed effects estimation with cross-section fixed effects is not possible. Instead, we include country-group fixed effects and time fixed effects. Time fixed effects, however, have never been significant and thus results are not reported here.

4.3.2. Data

We construct a panel data set from various sources.[7] The panel contains data for 64 countries and 3 years (1995, 2000, 2005). The panel is highly unbalanced and missings are systematic (OECD countries usually have a full set of observations whereas part of the non-OECD countries have only two or even only one observation). The explanatory variables are available for all countries and nearly all years. In contrast, Social Accounting data is not frequently surveyed in all countries. For most developing and transition countries only one SAM is available.[8] In total, we have 135 observations.

The data on transport margins has been collected from input-output-tables from different sources, mainly the International Food Policy Research Institute (IFPRI), Eurostat and the OECD. Data on road and rail road length as well as most of the control variables are from the World Development Indicators (WDI) Database. The country classification in income groups follows the World Bank classification. The regional groups are chosen as in Fay & Yepes [2003]. Tables 4.1 and 4.2 show descriptive statistics.

The spending for transport ranges between 0.4% and 15% of sectoral production costs, 3.5% on average, in agricultural sectors and between 1 and 15% over all sectors, 6% on average. The countries in our sample have on average, 788 m of paved roads per km^2 of surface where the lowest transport network density is at only 3m/km^2 and the highest at 6086 m/km^2. The GDP per capita lies between 254 US-$ and 51,934 US-$. On average, 168 persons live on one km^2 of surface. The least concentrated country is populated by only 2.4 persons/km^2 and the most densely populated has over 3100 persons on the same surface. On average, more than half of the population lives in towns, only 12% in the most rural country and over 97% in the most urbanized. The climate conditions vary substantially across the countries. The temperature index lies between 7 and 1600 degrees Celsius. The highest maximum mean temperature is at about 32°C, the lowest minimum mean temperature is at about -11°C.

[7] A detailed overview of the different data sources is included in table 4.7 in the appendix.

[8] The availability of SAMs also determines the total number of countries, we can only use Social Accounting Matrices where transportation is explicitly included and not aggregated with trade services and which have been updated between the periods of our panel.

Table 4.1.: Descriptive statistics - Dependent variables and control variables

Variable	transport margins		paved roads/ surface	gdp/ capita US$	population density	urban population as % of total	temperature index	precipitation in mm	Agricultural land as % of total	Motor vehicles per 1000 persons	% of labor force with tertiary education	Corruption index
Abbrev.	m_{ag}	m_{all}	transport	gdpc	popdens	urban	temp	precip	agrland	vehicl	edu	corrup
Mean	0.035	0.060	0.788	13264.90	167.99	65.67	503.27	937.49	44.57	384.65	24.86	5.80
Median	0.026	0.058	0.371	8197.10	95.18	67.40	372.69	746.175	49.57	442.00	23.80	5.70
Std. dev.	0.027	0.026	0.966	12440.90	378.32	18.63	407.66	530.80	20.52	210.98	12.87	2.50
Min	0.004	0.011	0.003	253.48	2.43	12.02	6.85	54.74	3.298	8.00	3.00	1.50
Max	0.149	0.147	6.086	51934.26	3112.25	97.26	1595.14	2922.00	84.88	738.00	83.200	10.00
# obs	135	135	135	135	135	135	113	114	133	58	107	120

Table 4.2.: Descriptive statistics - Dummy variables

	Regional Dummies							Income dummies			Year dummies		
	Eastern Europe / Central Asia	Middle East / North Africa	Sub Sahara Africa	Latin America	High Income	East Asia / Pacific	South Asia	High	Middle	Low	1995	2000	2005
Mean	0.141	0.007	0.074	0.111	0.578	0.037	0.052	0.578	0.348	0.074	0.336	0.343	0.321
Median	0.000	0.000	0	0	1	0	0	1	0	0	0	0	0
Std. dev.	0.350	0.086	0.251	0.316	0.495	0.190	0.223	0.495	0.479	0.251	0.474	0.477	0.469
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	1	1	1	1	1	1	1	1	1	1	1	1	1
# obs	19	1	10	15	78	5	7	78	47	10	45	46	44
# countries	9	1	7	12	29	3	3	29	27	8			

The sample consists of 64 countries of which 29 are high, 27 middle and 8 low income countries, the low and middle income countries are located as follows: three Eastern Asian and three Southern Asian countries, nine eastern European and Central-Asian countries, twelve Latin American countries, one Middle East and seven countries from Sub-Sahara Africa. Given the fact that the sample is biased in favor of high income countries (app. 60% of the observations are from high income countries) we include income group dummies to control for this and estimate country-group wise in addition to the pooled estimation. The observations with very low margins, very high temperatures and very low degrees of urbanization have been excluded from the relevant regressions after distributional tests.

4.4. Results

4.4.1. Pooled estimation

Table 4.3 summarizes the regression results for different specifications with the transport margin in agricultural sectors (m_{ag}) as dependent variable in specifications (1)-(5). This margin in agriculture should be more sensitive to bad roads compared to m_{all} which is the weighted average of the transport margins in all sectors.[9] All variables have been used in natural logarithms such that the results can be interpreted as elasticities.[10]

The regressions clearly show that for the complete sample an increased availability of roads significantly reduces the transport margin in agricultural sectors. This effect is robust in a number of different specifications. The sign remains negative across the different estimations. However, the effect is only significant if we control for distinct country characteristics such as the income group classification or the geographical location.[11] All these may be interpreted as indicators that clearly differ between industrialized and developing countries. The estimated elasticity of the transport cost measure with respect to changes in the road density lies between 0.077 and 0.334 in absolute terms.

The other explanatory variables clearly add explanatory power to the estimation but are mostly insignificant. We find a fairly robust positive relationship between the degree of urbanization and transport costs in agricultural sectors, which is related to the fact that in highly urbanised countries the distance between production site and sales market for agricultural products is highest.

[9] Results for all sectors are described in the columns (6)-(10) in table 4.3, results for other specifications are shown in tables 4.8, 4.11 and 4.12.

[10] In addition, the use of logarithms significantly reduces the number of outliers which is important here, given the rather small sample and the fact that there is a large difference in magnitude between the different variables (*gdpc* has much higher absolute values than the other variables).

[11] The coefficient is also significantly negative if we control for the level of education in the labor force. The education variable itself is, however, not siginificant. This result is shown in table 4.11 in the appendix.

Table 4.3.: Results from pooled OLS regression whole sample

Spec. No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
dependent	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$
# of obs	113	114	114	105	105	114	106	106	105	105
ln(trans)	-0.102	-0.292***	-0.297***	-0.336***	0.167	-0.195***	-0.167***	-0.168***	-0.194***	-0.183
	(-1.083)	(-3.757)	(-3.317)	(-4.386)	(0.841)	(-4.36)	(-3.71)	(-3.358)	(-4.812)	(-1.304)
ln(gdpc)	-0.219*	-0.126	-0.107	-0.061	-0.009	0.134*	-0.95*	0.155	-1.37**	-1.382**
	(-1.887)	(-0.947)	(-0.878)	(-0.299)	(-0.045)	(1.688)	(-1.723)	(1.82)	(-2.336)	(-2.441)
ln(popdens)	0.085	0.129*	0.112	0.145**	0.206***	0.108***	0.086**	0.095**	0.133***	0.135***
	(0.925)	(1.806)	(1.434)	(2.116)	(3.494)	(3.13)	(2.351)	(2.567)	(4.254)	(4.472)
ln(urban)	1.129***	0.118	1.797***	0.137	0.331	-0.394	-0.129	0.049	0.012	0.019
	(3.047)	(0.28)	(3.648)	(0.295)	(0.719)	(-1.476)	(-0.508)	(0.206)	(0.062)	(0.094)
ln(temp)	0.033	0.028	0.061*	0.038	0.005	0.003	0.002	-0.004	0.035	0.034
	(0.701)	(0.817)	(1.69)	(0.975)	(0.124)	(0.093)	(0.058)	(-0.143)	(1.3)	(1.193)
ln(precip)	0.139	0.015	0.22*	-0.004	0.08*	-0.156**	-0.192***	-0.178*	-0.186**	-0.185**
	(1.366)	(0.155)	(1.678)	(-0.031)	(1.587)	(-2.009)	(-2.802)	(-1.704)	(-2.6)	(-2.367)
ln(agrland)	-0.17									
	(-1.462)									
$\ln(gdpc)^2$							0.061**		0.085**	0.086***
							(2.001)		(2.584)	(2.694)
ln(corrup)				-0.224	-0.712**				-0.089	-0.101
				(-0.68)	(-2.011)				(-0.588)	(-0.504)
ln(corrup)*ln(transp)					-0.304***					-0.007
					(-3.041)					(-0.095)
low income		-2.742***		-2.886***	-1.654**	-1.15***	-1.182**		-1.382***	-1.357**
		(-5.222)		(-4.985)	(-2.145)	(-2.926)	(-2.62)		(-2.945)	(-2.258)
middle income		-0.359		-0.437	-0.269	-0.271	-0.177		-0.358	-0.354
		(-1.539)		(-1.154)	(-0.901)	(-1.387)	(-1.014)		(-1.621)	(-1.505)
East Asia/Pacific			0.094					0.239		
			(0.019)					(0.933)		
Europe/Centr. Asia			-0.095					-0.241		
			(-0.405)					(-0.991)		
Latin America			-0.959***					-0.186		
			(-2.56)					(-0.867)		
South Asia			1.352***					0.307		
			(2.608)					(0.991)		
Sub Sah. Africa			-0.005					-0.245		
			(-0.006)					(-0.927)		
constant	-7.29***	-3.854***	-12.716***	-4.154***	-0.526***	-1.908*	2.006	-3.762***	3.025	3.05
	(-4.753)	(-2.782)	(-5.798)	(-2.492)	(-3.068)	(-1.77)	(0.801)	(-3.427)	(1.155)	(1.184)
R^2	0.194	0.344	0.321	0.398	0.408	0.195	0.228	0.19	0.267	0.267
adj. R^2	0.140	0.294	0.248	0.335	0.345	0.134	0.155	0.103	0.189	0.18

t-statistics in parantheses, ***, **, * indicate significance on 1%, 5% and 10% level respectively

Results for the impact of GDP per capita are ambiguous. In order to check whether this is due to a non-linear relationship between GDP and transport costs, we add $gdpc^2$ in estimation (a12). The coefficients for *gdpc* and $gdpc^2$ have opposing mathematical signs, which is an indicator for a non-linear relationship between the dependent variable and the GDP per capita. However, none of the two coefficients are significant and the squared term adds only little explanatory power.[12]

The inclusion of the climate indicators seems to be important as these significantly increase the explanatory power even though they are only significant in equation (3). Both high temperatures and high quantities of precipitation increase transport costs, which is intuitive as these extreme weather conditions hinder transport even if roads are appropriate. A high share of agriculturally used land is associated with slightly lower transport margins in agriculture, supposedly due to economies of scale. The effect is not significant in the complete sample.

The two dummy variables for low and middle income countries are negative and the low income dummy is highly significant. If these dummies are alternatively split into five regional dummies for the low and middle income countries, only the Latin America dummy and the South Asia dummy are significant and the overall explanatory power of the estimation is lower. However, the significance of these dummies for income groups or geographical location is a strong indication for a substantial difference between high income countries on the one hand and developing and transition countries on the other hand.

One possible explanation for differences in transportation costs between high income and middle and low income countries, apart from the climate (which adds some explanatory power but is not significant), might be that high levels of corruption lead to higher transaction costs and longer transport times due to frequent controls on the way. Indeed, corruption is strongly negatively correlated with GDP per capita (see figure 4.1) and might thus explain the significance of the income dummies if it plays a role in determining transport costs.[13]

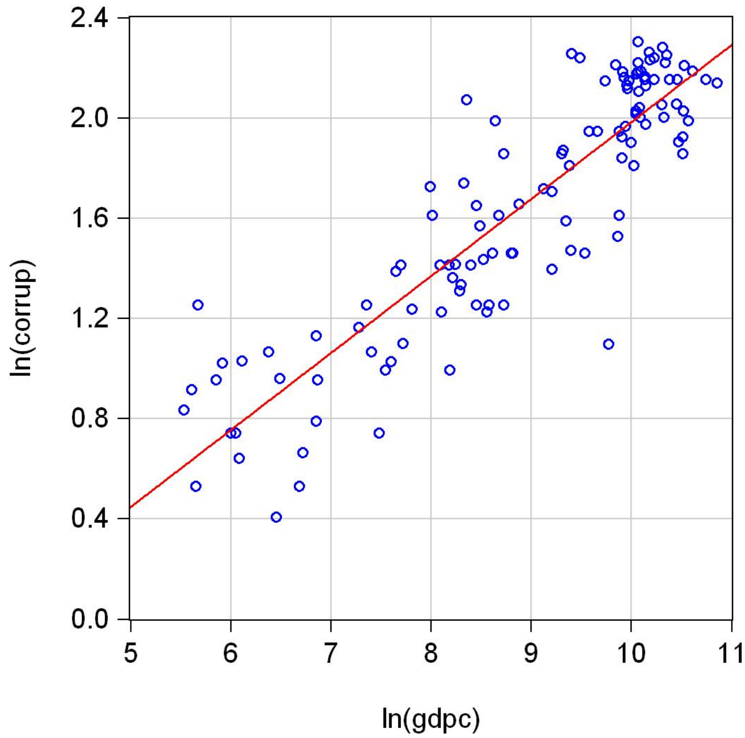
In order to take this into account we include *transparency international's perceived corruption index* into estimations (4) and (5). The inclusion of the index increases the adjusted R^2 by 1.7 percentage points. The coefficient has the expected negative sign but is not significant.

As we believe that the effectiveness of roads might be conditional on the absence of corruption we include an interaction term between the corruption index and the road density in the last specification. Surprisingly, this strongly affects the results. The ex-

[12] See table 4.11 in the appendix.

[13] Please note the corruption index is defined between 0 and 10 where high levels of the index stand for low levels of corruption.

Figure 4.1.: Correlation between corruption and GDP per capita



planatory power rises, the coefficient of road density switches from significantly negative to insignificantly positive and the coefficient of the corruption index increases and is now significant, too. The positive coefficient for road density indicates that at very high levels of corruption (i.e. corruption index = 0) an increase in road density could increase transport costs. Calculating the mean effect of road density on transport margins in agriculture at mean corruption level gives a coefficient for $ln(trans)$ of -0.331 with a t-value of -4.786.[14] In other words the effectiveness of roads is strongly conditional on the absence of corruption, at the mean corruption level in the complete sample, the cost reduction from a 1% increase in road density is roughly 0.3%. However the income group dummies remain significant even though their influence is lower if corruption is controlled for.

Medium and low income countries have lower levels of agricultural transport costs, the OECD member status does not influence the results. Time fixed effects have not been significant.[15]

The relation between the transport network density and the transport costs for the complete sample is confirmed not only for the agricultural sectors but also for the weighted transport expenditure of all sectors. These results are shown in the last five

[14] All mean effects are summarised in table 4.6.
[15] Not shown here to simplify the exposition.

colums of table 4.3. We consistently find negative coefficients for transport networks as well. However, the influence of transport networks on the weighted transport costs in all sectors is much lower. In addition, the explanatory power of the estimations is substantially lower compared to the estimations for the agricultural sector.

Interestingly, the non-linearity of transport costs with respect to *gdpc* is significantly confirmed here in contrast to the results for m_{ag}. The GDP has a significant influence on transport costs in four out of the ten specifications. The influence of GDP is positive and switches to negative if $ln(gdpc)^2$ is included. The influence of $ln(gdpc)^2$ is significantly positive if included. This indicates a diminishing negative influence of the GDP on transport costs. The signs of most other coefficients are in line with the results for agricultural transport costs but the magnitudes are lower as well. Time fixed effects have been insignificant here, either. We do observe a significant coefficient for the low income dummy but not for the middle income dummy. Geographical dummies do not have significant influences on transport costs over all sectors.

The results for the inclusion of corruption are not robustly confirmed here. Even though the inclusion of corruption increases the explanatory power, the coefficient of the index as well as the one of the interaction term are highly insignificant and close to zero. Calculating the effect of transport on the margin at mean corruption gives a coefficient of -0.194 with a t-value of -4.735. This is comparable to the result in equation (9), thus we do not confirm an interaction effect here.

The somehow weaker results for the weighted transport margin in all sectors might partly result from the fact that the production structure differs substantially across countries and thus, as we use sectoral production as weights, the transport cost measure is very heterogeneous compared to agricultural production which is more comparable across countries.

4.4.2. Country group estimations

The fact that the income groups have been found to be consistently significant as well as some of the geographical dummies even after controlling for a number of country characteristics like climate, population density, urbanization, land use, education and corruption indicates that there might be a structural difference in the determinants of transport costs between high income countries and developing and transition countries. Hence, we divide our sample into a high income and a medium and low income sample.[16] We run the same regressions as shown above in order to isolate country group specifics. We indeed find substantial differences between the two subsamples.

Table 4.4 shows the results for the margin in agricultural sectors. Estimations (1) -

[16] The descriptive statistics for the two subsamples are shown in the appendix in tables 4.9 and 4.10.

(5) are for the high income countries only, whereas estimations (6) to (11) only comprise low and medium income countries.[17]

It is obvious that the two samples produce quite differing results. For *high income countries* we mostly confirm the results obtained in the complete sample. We find a significantly negative relationship between road infrastructure and transport costs. The estimated coefficients are even higher compared to table 4.3. Still, the influence of GDP per capita is ambiguous. Densely populated countries have higher transport costs in agriculture as well as highly urbanised countries. Supposedly this is due to the fact that agricultural products have to be carried long ways in these countries. In contrast, higher shares of agriculture in total land use lead to lower transport costs in this sector, which may be attributed to economies of scale in transportation.

We also confirm the positive influence of corruption on transport costs (negative coefficient). However, we do not observe an interaction effect. The coefficient of the interaction term is insignificant and its inclusion adds virtually no explanatory power.

[17]Note, to simplify matters not all specifications presented above for the whole sample are replicated here. We only show those with most explanatory power.

Table 4.4.: Results from pooled OLS regression for margin in agricultural sectors, subsamples

Spec. No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
dependent	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$
Sample	high	high	high	high	high	low&med.	low&med.	low&med.	low&med.	low&med.	low&med.
# of obs	78	73	73	69	69	57	35	36	37	32	32
ln(trans)	-0.227*	-0.463***	-0.38***	-0.56***	0.439	-0.013	0.271	0.302*	0.203	0.228*	1.578**
	(-1.689)	(-7.831)	(-5.724)	(-9.046)	(0.415)	(-0.142)	(2.111)	(1.898)	(1.465)	(1.898)	(2.256)
ln(gdpc)	-0.383*	-0.074	-0.199	0.313	0.282	0.092	-0.095	-0.413	-0.097	-0.482	-0.334
	(-1.99)	(-0.493)	(-1.366)	(1.569)	(1.508)	(0.477)	(-0.219)	(-0.816)	(-0.276)	(-1.031)	(-0.674)
ln(popdens)	0.031	0.193***	0.169***	0.207***	0.265***	0.112	0.001	-0.241	-0.199	-0.035	-0.318
	(0.277)	(4.046)	(4.101)	(4.099)	(3.06)	(0.781)	(0.053)	(-0.693)	(-0.7)	(-0.132)	(-0.872)
ln(urban)	0.863*	0.831	1.123*	1.407**	1.329**	0.571	1.055	1.406	2.476***	1.586	0.815
	(1.699)	(1.559)	(1.932)	(2.326)	(2.191)	(1.322)	(1.091)	(1.302)	(3.037)	(1.567)	(0.694)
ln(temp)		0.105*	0.208**	0.071	0.071		0.874***	0.969***	0.827***	0.97***	0.817***
		(1.925)	(2.097)	(1.344)	(1.29)		(3.665)	(4.39)	(4.108)	(3.981)	(3.981)
ln(precip)		0.078	0.116	0.223	0.201		-0.145	-0.552**	-0.328	-0.461	-0.537**
		(0.335)	(0.494)	(0.927)	(0.861)		(-0.464)	(-2.445)	(-1.298)	(-1.344)	(-2.048)
ln(agrland)			-0.245*					0.419			
			(-1.695)					(0.851)			
ln(corrup)				-1.452***	-1.382***					0.585	-2.478
				(-3.883)	(-3.971)					(0.766)	(-1.571)
ln(corrup)*ln(transp)					-0.496						-1.084**
					(-0.943)						(-2.005)
East Asia/Pacific									0.794*		
									(1.928)		
Latin America									-0.321		
									(-0.533)		
South Asia									1.954***		
									(4.536)		
Sub Sah. Africa									1.294***		
									(3.083)		
C	-3.903*	-8.592***	-8.451***	-12.898***	-12.536***	-6.925***	-10.907***	-8.14***	-14.72***	-9.116***	-0.662
	(-1.811)	(-3.738)	(-3.485)	(-4.708)	(-4.735)	(-4.2)	(-4.44)	(-3.238)	(-5.495)	(-3.433)	(-0.131)
R^2	0.211	0.372	0.404	0.493	0.503	0.145	0.442	0.293	0.651	0.407	0.435
adj.R^2	0.168	0.315	0.339	0.435	0.437	0.079	0.323	0.069	0.517	0.234	0.197

t-statistics in parenthesis, ***, **, * indicate significance on 1%, 5% and 10% level respectively

The picture is quite different for the middle and low income sample. Here we mostly find positive but sometimes insignificant coefficients for the road density. Hence, in middle and low income countries additional roads have no effects on transport costs or may even increase these.

We do not find significant effects of *gdpc* or population density but we confirm the cost increasing influence of urbanization. The climate indicators especially the temperature index are the only determinants that are significant in most specifications to the contrary of the high income and the complete sample results. For the low and middle income sample we find a strong cost increasing influence of temperature and a cost-reducing influence of precipitation.

The inclusion of corruption increases the explanatory power. However corruption is only significant if the interaction term is included as well. In this case we find a very high and positive coefficient for roads and high and negative coefficients for corruption and the interaction term. The R^2 is much higher compared to the other specifications, except for equ. (9). Thus, for transport costs in the agricultural sector in developing and transition countries we cannot confirm that roads reduce these. However, we clearly find that corruption hinders improvements in transport costs. At the mean level of corruption in this sample, the effect of transport infrastructure on transport margins in agriculture is 0.3341 with a t-value of 2.06. Thus, the mean level of corruption in developing countries is so high that additional roads are not only inefficient concerning transport costs in agriculture, they even increase costs in this sector, supposedly due to inefficient allocation of road investments. At very high levels of corruption (index close to 0) additional roads may even increase transport costs overproportionally (coefficient > 1).

What has been found for the margin in agricultural sectors for the two country groups is not true for the weighted margin over all sectors. For both income groups we confirm the negative influence of road infrastructure on tranport costs but with weaker explanatory power and lower coefficients. We consistently confirm the cost-increasing influence of population density and urbanization.

Table 4.5.: Results from pooled OLS regression for margin in all sectors, subsamples

Spec. No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
dependent	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$
Sample	high	high	high	high	low&med.	low&med.	low&med.	low&med.	low&med.
# of obs	78	73	71	71	57	39	39	34	34
ln(trans)	-0.033	-0.137***	-0.109***	0.483	-0.051	-0.414***	-0.375**	-0.434***	0.269
	(-0.333)	(-2.956)	(-2.685)	(1.07)	(-0.648)	(-4.126)	(-2.671)	(-5.349)	(0.729)
ln(gdpc)	-0.09	0.1	0.121	0.102	0	0.098	0.096	0.356*	0.439**
	(-0.751)	(1.273)	(1.525)	(1.378)	(0.001)	(0.504)	(0.356)	(1.737)	(2.212)
ln(popdens)	-0.042	0.078***	0.093***	0.128***	-0.026	0.932***	1.151***	0.996***	0.849***
	(-0.517)	(2.736)	(3.156)	(2.973)	(-0.202)	(4.468)	(4.814)	(4.861)	(3.349)
ln(urban)	0.207	0.18	0.399**	0.353**	0.048	0.73*	1.044*	0.63	0.219
	(0.582)	(0.609)	(2.247)	(2.086)	(0.277)	(1.824)	(1.985)	(1.565)	(0.487)
ln(temp)		-0.101***	-0.079***	-0.079***		0.081**	0.049	0.159**	0.073
		(-3.718)	(-3.109)	(-3.169)		(2.155)	(1.136)	(2.313)	(0.923)
ln(precip)		-0.082	-0.187*	-0.2**		-0.494***	-0.793***	-0.521***	-0.554***
		(-0.766)	(-1.964)	(-2.131)		(-3.468)	(-4.122)	(-2.902)	(-3.423)
ln(corrup)			-0.013	0.028				-0.775	-2.382**
			(-0.06)	(0.132)				(-1.457)	(-2.685)
ln(corrup)*ln(transp)				-0.294					-0.566*
				(-1.305)					(1.95)
Europe/Centr. Asia							-0.943**		
							(-2.579)		
Latin America							-0.279		
							(-0.668)		
South Asia							-0.697		
							(-1.626)		
Sub Sah. Africa							-0.26		
							(-0.782)		
constant	-2.661*	-3.824***	-4.399***	-4.184***	-3.218**	-8.532***	-7.761***	-9.828***	-5.412
	(-1.729)	(-3.515)	(-3.445)	(-3.364)	(-2.465)	(-5.151)	(-2.987)	(-5.739)	(1.666)
R^2	0.053	0.235	0.319	0.335	0.035	0.363	0.452	0.474	0.541
adj. R^2	0.001	0.165	0.241	0.246	-0.04	0.244	0.256	0.332	0.395

t-statistics in parantheses, ***, **, * indicate significance on 1%, 5% and 10% level respectively

The countries differ in the influence of climate and in the influence of corruption. We find a strong influence of temperature on transport costs in both country groups but with opposing signs. In high income countries higher temperatures reduce the transport margin whereas in middle and low income countries higher temperatures increase the transport margin. This may be explained by differences in technology. For precipitation, the influence is low and partly insignificant in industrialised countries but highly negative in developing countries.

We cannot confirm the positive influence of corruption for high income countries, but we find it to be of importance for middle and low income countries, we see a rise in R^2 after inclusion of the corruption index. Still, the corruption index is only significant after controlling for an interaction between corruption and roads. The coefficient for road networks becomes insignificant. Calculating mean effects for table 4.5 leads to a coefficient of transport at mean corruption of -0.089 in high income countries and -0.380 in middle and low income countries. Hence, the inefficiency of road allocation that has been found for the agricultural sector in developing and transition countries does not apply for the margin in all sectors. Still, we confirm the interaction effect and find roads impact to be conditional on corruption, only the mean level of corruption is not prohibitive for cost reduction in all sectors but only in agricultural sectors.

Table 4.6.: Effects of ln(transnet) on transport margin at mean corruption

Specification	Sample	Coefficient	t-statistic	P-Value
$ln(m_{ag})$	all	-0.331***	-4.786	0.000
$ln(m_{all})$	all	-0.194***	-4.735	0.000
$ln(m_{ag})$	high	-0.527***	-7.516	0.000
$ln(m_{all})$	high	-0.089**	-1.999	0.050
$ln(m_{ag})$	low&med	**0.334****	2.061	0.051
$ln(m_{all})$	low&med	-0.380***	-3.516	0.000

4.4.3. Robustness

All estimations have been done using heteroscedasticity-robust standard-errors. The results are perfectly robust disregarding whether the Newey-West-specification or the White-specification is used. Based on the Jarque-Bera-Test, we do not reject the null-hypothesis of normally distributed residuals in any of our estimations.

The results are also robust with respect to the sample. We have run estimations excluding the smallest and largest countries and obtained similar results as shown here. However, we are not able to exclude more than one of the developing countries at a time given the small number of developing countries in the sample.

As the quality of roads has an influence on transport costs, too [this is e.g. found by

Teravaninthorn & Raballand, 2009, and others] and this aspect is not covered by our approach we have included either the share of paved roads in the total network of the respective country or the share of expressways in the paved network of the country in equations (a20)-(a21) and (a23)-(a24) in table 4.6 in the appendix as measures for the average road quality in the country. These explanatory variables add slightly to the explanatory power but do not change the general results described above. However, data on the expressways was only available for the years 2000 and 2005 and thus the inclusion of this indicator reduces the number of observations substantially. The same is true for the number of vehicles in a country which might be used as a proxy for the availability of transport technology. However the data in the WDI on vehicles is very incomplete.

In order to address the problem that the sample splitting leads to a substantially reduced number of degrees of freedom we have alternatively estimated equations (a22) and (a25) with triple interaction terms including the income group dummys. The results are in table 4.6 and are not in contradiction to the results found with separate samples. In addition it is visible that the influence of corruption is mainly driven by the low income countries. However, the mean effect is also significant for middle income countries (not shown).

4.5. Conclusions

We have shown by means of pooled OLS estimations in a sample comprising high, medium and low income countries that investments in longer and better roads have the potential to significantly reduce the transport spending. However, this result is of particular importance for agricultural production and transportation of agricultural goods. Even though the negative effect of roads on transport costs is confirmed for all sectors, the importance of the effect is substantially lower on average compared to agricultural transport costs. Other explanatory variables might be more important in industrial sectors.

These results for the complete sample and the confirmation of these for the high income sample show that our proxy for transport costs, the transport margin, is a good and internationally comparable measure of transaction costs from transportation. Our results are in line with most findings for high income countries that use other measures such as the tariff equivalent costs of bad roads or vehicle operation costs.

Splitting the sample into high income countries on the one hand and low and medium income countries on the other hand reveals substantial differences between country groups. In low and medium income countries we find climate and most importantly the level of perceived corruption to be more important in determining transport costs than the availability of infrastructure. We find substantial differences between industrial and developing and transition countries that should be taken into account when infrastructure projects are planned in low and middle income countries.

We find an interaction effect between road status and corruption that might lead to negative effects from roads at very high levels of corruption, supposedly due to inefficient planning and non-maintenance of existing roads. The effectiveness of infrastructure programs might thus be conditional on the reduction of corruption in these countries. This is in line with Aschauer [2000] and Hulten [1996] who argue concerning public investment in general that not only the amount of public capital is important but also how efficiently it is invested and used. Especially in the agricultural sector in developing and transition countries this interaction effect is crucial. The mean level of corruption is so high that it is prohibitive for cost reductions in agriculture. Thus, the agricultural sector in these countries does not benefit from higher levels of infrastructure and this is partly due to corruption.

This paper contributes to the literature on infrastructure investment by developing and applying an internationally comparable measure of transport costs which can be calculated for a large and growing number of countries. We isolate important determinants of transport costs and provide an insight on sectoral differences concerning roads' effect on transport costs. Most importantly, we find strong support for the hypothesis that the positive experiences from large infrastructure programs in industrial countries cannot easily be applied to developing and transition countries as other important circumstances should be present as well.

We conclude that investment in transport infrastructure can have highly positive effects especially on agricultural production and the efficient marketing of agricultural products. However, this is conditional on low levels of corruption and efficient planning and use of the infrastructure as well as on the climatic circumstances.

C. Appendix

Table 4.7.: Data sources & description

Variable	Country	Data Source	Description
transport margins (m)	Argentina	IFPRI	Own calculations based on the Social Accounting Matrices or Input-Output tables. Calculation: For each sector we compute: Sectoral spending on transport/Total sectoral production and marketing cost, we then aggregate the margins by calculating an output-weighted average.
	Australia	OECD	
	Austria	Eurostat	
	Bangladesh	IFPRI	
	Belgium	Eurostat	
	Bolivia	IFPRI	
	Brazil	IFPRI	
	Bulgaria	Eurostat	
	Canada	OECD	
	Chile	IFPRI	
	China	OECD	
	Colombia	IFPRI	
	Costa Rica	IFPRI	
	Czech Republic	Eurostat	
	Denmark	Eurostat	
	Egypt	IFPRI	
	El Salvador	IFPRI	
	Estonia	Eurostat	
	Finland	Eurostat	
	France	Eurostat	
	Germany	Eurostat	
	Ghana	IFPRI	
	Great Britain	Eurostat	
	Greece	Eurostat	
	Honduras	IFPRI	
	Hungary	Eurostat	
	India	National statistics	
	Indonesia	IFPRI	
	Ireland	Eurostat	
	Israel	OECD	
	Italy	Eurostat	
	Japan	OECD	
	Kenya	IFPRI	
	Latvia	Eurostat	
	Lithunia	Eurostat	
	Luxemburg	Eurostat	
	Macedonia	Eurostat	
	Malta	Eurostat	
	Mexico	IFPRI	
	Netherlands	Eurostat	
	New Zealand	OECD	
	Nigeria	IFPRI	
	Norway	OECD	
	Paraguay	IFPRI	
	Peru	IFPRI	
	Poland	Eurostat	
	Portugal	Eurostat	
	Romania	Eurostat	
	Russia	National statistics	
	Slovakia	Eurostat	
	Slovenia	Eurostat	
	South Africa	IFPRI	
	Spain	Eurostat	
	Sweden	Eurostat	
	Switzerland	National statistics	
	Tanzania	IFPRI	
	Thailand	IFPRI	
	Turkey	Eurostat	
	Uganda	IFPRI	
	Ukraine	National statistics	
	Uruguay	IFPRI	
	USA	OECD	
	Vietnam	IFPRI	
	Zambia	IFPRI	

road density (transp)	all	World development indicators	The road density has been calculated based on the indicators: "roads, total network","roads, paved percent" and "surface, total". It is defined as paved roads/km^2 surface
GDP per capita (gdpc)	all	World development indicators	GDP per capita in constant US$
population density (popdens)	all	World development indicators	
Temperature index (temp)	all	World metereological organization	The index has been calculated as yearly maximum squared + yearly minimum squared
Precipitation (precip)	all	World metereological organization	Precipitation per year in mm
urbanization (urban)	all	World development indicators	urban population as % of total
agricultural land(agrland)	all	World development indicators	Agricultural land as % of land area
Corruption	all	Transparency international	The perceived corruption index is defined between 0 and 10 where 10 means "no corruption"
Education (edu)	all	World development indicators	% of labor force with tertiary education
Motor vehicles (vehicl)	all	World development indicators	Motor vehicles per 1000 persons
% Paved roads (paved)	all	World development indicators	Paved roads as % of total network
% Expressways (exprway)	all	CIA World Factbook	Expressways as % of total paved network

Table 4.8.: Results from pooled OLS regression whole sample - additional specifications

Spec. No.	(a1)	(a2)	(a3)	(a4)	(a5)	(a6)	(a7)	(a8)	(a9)	(a10)
dependent	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$
	135	135	135	135	114	135	135	135	135	114
	-0.077**	-0.087*	-0.074	-0.061	-0.152*	-0.007	-0.045	-0.026	-0.026	-0.141***
	(-2.003)	(-1.738)	(-0.718)	(-0.633)	(-1.727)	(-0.284)	(-1.392)	(-0.414)	(-0.408)	(-3.041)
		0.02	0.01	-0.175	-0.16		0.076*	0.063	0.06	0.17**
		(0.301)	(0.109)	(-1.611)	(-1.459)		(1.932)	(1.038)	(0.843)	(2.311)
			-0.02	0.002	0.083			-0.029	-0.029	0.096**
			(-0.172)	(0.02)	(0.877)			(-0.404)	(-0.397)	(2.131)
				0.901***	1.031***				0.014	-0.105
				(3.247)	(2.785)				(0.09)	(-0.518)
ln(temp)					-0.005					-0.01
					(0.073)					(-0.386)
ln(precip)					0.091					-0.123
					(1.278)					(-0.463)
constant	-3.749***	-3.935***	-3.751***	-5.921***	-7.909***	-2.916***	-3.632***	-3.364***	-3.398***	-3.592***
	(-45.391)	(-6.404)	(-2.748)	(-4.086)	(-5.037)	(-56.643)	(-9.601)	(-3.874)	(-3.657)	(-4.041)
R^2	0.029	0.03	0.031	0.108	0.174	0.001	0.035	0.038	0.038	0.122
adj. R^2	0.022	0.015	0.009	0.081	0.128	-0.007	0.021	0.016	0.009	0.072

t-statistics in parantheses, ***, **, * indicate significance on 1%, 5% and 10% level respectively

Table 4.9.: Descriptive statistics high income sample

Variable	transport margins		paved roads/ surface	gdp/ capita US$	population density	urban population as % of total	Temperature index	precipitation in mm	Agricultural land as % of total	Motor vehicles per 1000 persons	% of labor force with tertiary education	Corruption index
Abbrev.	m_{ag}	m_{all}	transport	gdpc	popdens	urban	temp	precip	agrland	vehicl	edu	corrup
Mean	0.0314	0.0639	1.213	21120.54	217.34	73.61	340.12	876.16	42.40	524.77	26.86	7.27
Median	0.0241	0.0626	0.926	21330.45	109.58	73.90	295.30	747.00	49.18	521.00	26.50	7.55
Std. dev.	0.0247	0.0240	1.063	10737.43	479.02	11.88	218.30	419.41	21.04	110.15	12.49	1.80
Min	0.0035	0.0108	0.032	2858.17	2.43	49.50	6.85	383.92	3.40	256.00	8.60	2.99
Max	0.1289	0.1234	6.086	51934.26	3112.25	97.26	1068.50	2375.82	71.83	738.00	83.20	10.00
# obs	78	78	78	78	78	78	75	75	76	35	75	74

Table 4.10.: Descriptive statistics low & middle income sample

Variable	transport margins		paved roads/ surface	gdp/ capita US$	population density	urban population as % of total	Temperature index	precipitation in mm	Agricultural land as % of total	Motor vehicles per 1000 persons	% of labor force with tertiary education	Corruption index
Abbrev.	m_{ag}	m_{all}	transport	gdpc	popdens	urban	temp	precip	agrland	vehicl	edu	corrup
Mean	0.0388	0.0561	0.1917	2288.48	97.79	54.26	20570.07	1055.42	47.28	171.41	20.19	3.37
Median	0.0378	0.0534	0.1067	1775.14	71.53	58.40	819.36	745.35	50.46	149.84	19.00	3.15
Std. dev.	0.0294	0.0281	0.2411	1858.78	128.09	20.67	87303.57	688.18	19.50	133.42	12.69	1.33
Min	0.0052	0.0120	0.0026	253.48	6.81	12.02	95.50	54.74	3.30	8.00	3.00	1.50
Max	0.1494	0.1472	1.0765	7197.17	872.09	90.50	417559.03	2922.00	84.88	467.00	66.10	7.94
# obs	57	57	57	57	57	57	40	39	57	23	32	46

Table 4.11.: Results from pooled OLS regression for different additional specifications

Spec. No.	(a11)	(a12)	(a13)	(a14)	(a15)	(a16)	(a17)	(a18)	(a19)
dependent	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{all})$	$ln(m_{ag})$	$ln(m_{all})$
sample	complete	complete	complete	complete	high	high	high	low&med.	low&med.
# of obs	45	114	49	89	73	31	35	28	33
ln(transp)	-0.493***	-0.287***	-0.222***	-0.184***	-0.447***	-0.564***	-0.088	0.067	-0.254
	(-4.482)	(-4.128)	(-3.455)	(-4.161)	(-5.133)	(-5.706)	(-0.534)	(0.214)	(-1.298)
ln(gdpc)	-0.034	-1.344	0.406**	0.235***	-4.423	0.312	0.179	-1.94	0.598
	(-0.111)	(-1.586)	(2.483)	(2.778)	(-1.335)	(0.986)	(0.776)	(-0.578)	(0.371)
ln(popdens)	0.242***	0.127*	0.137***	0.113***	0.176**	0.275***	-0.031	-0.197	0.538
	(4.015)	(1.797)	(2.75)	(3.146)	(2.421)	(3.996)	(-0.222)	(-0.332)	(1.39)
ln(urban)	-0.237	0.329	-0.484	-0.2	0.79	1.358	-0.014	-0.365	0.300
	(-0.219)	(0.856)	(-0.951)	(-0.532)	(1.62)	(1.637)	(-0.025)	(-0.38)	(0.652)
ln(temp)	0.134	0.039	-0.015	-0.079**	0.15*	0.037		0.517	0.077**
	(1.036)	(0.759)	(-0.368)	(-2.415)	(1.804)	(0.536)		(1.224)	(2.173)
ln(precip)	0.009	-0.008	0.004	-0.201**	0.042	0.032		-0.217	-0.387**
	(0.024)	(0.068)	(0.029)	(-2.111)	(0.203)	(0.119)		(-0.506)	(-2.264)
ln(edu)	0.058			-0.096					
	(0.178)			(-0.79)					
ln(vehicl)	0.794**		-0.306*			1.641***	-0.754		
	(2.62)		(-1.945)			(3.772)	(-1.652)		
ln(corrup)						-2.449***			
						(-3.528)			
$\ln(\text{gdpc})^2$		0.068			0.231			0.133	-0.031
		(1.454)			(1.314)			(0.581)	(-0.291)
low income		-3.071***	-0.999**						
		(-5.128)	(-2.104)						
middle income		-0.377	-0.199						
		(1.541)	(-0.548)						
constant	-9.494**	0.712	-3.37**	-2.701*	11.971	-19.746***	0.288	4.287	-7.493
	(-2.222)	(0.203)	(-2.609)	(-1.983)	(0.756)	(-4.766)	(0.083)	(0.321)	(-1.203)
R^2	0.427	0.357	0.377	0.25	0.389	0.736	0.177	0.443	0.257
adj. R^2	0.257	0.301	0.233	0.185	0.323	0.641	0.036	0.209	0.049

Table 4.12.: Results from pooled OLS regression for different additional specifications

Spec. No.	(a20)	(a21)	(a22)	(a23)	(a24)	(a25)
dependent	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$
# of obs	105	63	105	105	63	105
ln(transp)	0.405*	0.357	-0.318***	-0.218	-0.028	-0.207***
	(1.981)	(1.000)	(-2.830)	(-1.424)	(-0.076)	(-2.747)
ln(gdpc)	0.016	0.357	-0.002	-1.301**	0.443	-1.574**
	(0.092)	(1.000)	(-0.010)	(-2.238)	(0.375)	(-2.449)
$\ln(gdpc)^2$				0.080**	-0.007	0.093***
				(2.483)	(-0.109)	(2.700)
ln(popdens)	0.253***	0.274***	0.121*	0.165***	0.179***	0.145***
	(3.640)	(5.514)	1.662	(3.270)	(4.295)	(2.927)
ln(urban)	0.755**	0.402	0.083	0.124	0.180	0.115
	(2.135)	(0.681)	(0.167)	(0.513)	(0.750)	(0.529)
ln(temp)	-0.025	-0.019	0.107*	0.027	0.015	0.004
	(-0.557)	(-0.344)	(1.769)	(1.011)	(0.447)	(0.143)
ln(precip)	0.184	0.350	-0.048	-0.153*	-0.035	-0.151**
	(1.225)	(1.258)	(-0.366)	(-1.949)	(-0.257)	(-2.161)
ln(corrup)	-0.91***	-1.121*	-0.201	-0.090	-0.212	-0.074
	(-2.765)	(-1.900)	(-0.584)	(-0.447)	(-0.695)	(-0.509)
ln(corrup)*ln(transp)	-0.45***	-0.42**		-0.018	-0.115	
	(-5.169)	(-2.344)		(-0.248)	(-0.609)	
ln(corrup)*ln(transp)*low			0.355			0.357***
			(1.628)			(5.720)
ln(corrup)*ln(transp)*med			0.139			-0.057
			(1.441)			(-1.046)
low income			-1.837	-1.146**		0.044
			(-1.577)	(-2.023)		(0.129)
middle income			-0.124	-0.343		-0.518
			(-0.336)	(-1.529)		(-1.618)
ln(paved)	0.106		-0.215	0.114		0.094
	(0.599)		(-1.230)	(0.822)		(0.665)
ln(exprway)		0.124			-0.112*	
		(1.181)			(-1.834)	
constant	-8.16***	-9.77***	-3.592	1.487	-7.531	3.203
	(-4.123)	(-3.505)	(-1.426)	(0.504)	(-1.424)	(0.993)
R^2	0.378	0.437	0.387	0.274	0.351	0.300
adj. R^2	0.320	0.342	0.307	0.179	0.226	0.200

5. How to model a child in school? A dynamic macro-simulation study for Tanzania

Abstract

Universal primary education is regarded as one of the key pillars of sustainable development. The positive influence of education on growth is supported by many empirical studies. However, the effects of education on labor supply, poverty reduction and welfare as well as subsistence agriculture are hardly traceable in an econometric setup, given the complex interactions and the long-term nature of education. An economy-wide dynamic simulation model provides a well-suited toolkit to analyze the effects of increased school provision in these aspects and provides insights into the intertemporal aspects of the schooling decision of children.

We develop a macro-economic model which explicitly includes education and human capital allocation and takes into account that the possibility of child labor increases the opportunity costs of human capital formation. In an application for Tanzania, we find that a large scale investment program in education might have a negative effect on both GDP growth and high skilled labor supply in the short-term but leads to higher GDP and welfare as well as significantly reduced child labor supply in the medium to long term.

"A sustainable end to world poverty as we know it, [..] require[s] that citizens are empowered to make positive choices and provide for themselves and their families."
United Nations Millennium Declaration

5.1. Introduction

Universal primary education ranges prominently among the Millennium Development Goals and is thus regarded as an important component of human development. In addition, education is widely believed to allow a country to access a higher steady state growth path by accumulating human capital. Consequently, education is one of the key pillars in the development strategies of all African countries and is also one of the main areas in which development aid is given on a large scale. Spending aid on education is also seen as a way to prevent *Dutch Disease* by reducing bottlenecks in scarce skill supply in the economy [See Heller, 2005].

Empirical cross-country evidence, such as Barro [1997] and Barro & Sala-i-Martin [2003], confirms that human capital measured by *years of schooling* has a positive influence on growth due to increased productivity of workers. Even though this finding is considered as "weak" by authors such as Schultz [1999], Pritchett [2001] and Topel [1997], consensus prevails that very poor education hinders economic development. Schooling does not only have direct positive effects on human development like lower child mortality and better health status. It also provides the population with the skills required for democratic participation and a strong civil society.

Pritchett [2001] suggests that the seemingly low productivity payoff in terms of wage increases for higher skilled workers might partly be explained by low demand for these skills and thus emphasizes the importance of considering the demand side of the labor market as well. Schultz [1999] highlights the differences between primary and higher education in terms of social costs and distributional impact and concludes that Africa might have put too much weight on higher education. This is also in line with findings that primary education in general produces the highest social rate of return [See also Dreher *et al.*, 2008]. Moreover, female primary education has a positive influence on child nutrition and children's health status and thus indirect positive effects on labor productivity. In addition, distributional aspects are of high importance given that reducing poverty is among the main objectives of aid policy. Gupta *et al.* [1999] and Gupta & Verhoeven [2001] add that the efficiency of public investment and public spending is important for the success of large scale investment in education.

Against the background of the summarized empirical literature the efficiency of public investment planning, the structure of the labor force and the structure of production and thus demand for labor need to be integrated in the analysis. In addition, a distinction of primary, secondary and higher education is required, i.e. a distinction between different skill levels in the labor force. The distributional as well as structural consequences in reaction to investment in education should be regarded as well. Jung & Thorbecke [2003], Agenor *et al.* [2008] and Maisonnave & Décaluwé [2010] suggest that a Computable General Equilibrium (CGE) model could provide additional insights in these respects. While Cloutier *et al.* [2008] investigate the effects of a reduction in education expenditure in Vietnam, Jung & Thorbecke [2003], Agenor *et al.* [2008] and Maisonnave & Décaluwé [2010] investigate the effect of an increase in public capital for education in different African countries. While Agenor *et al.* [2008] assume that only educated labor is used in production, Jung & Thorbecke [2003] in their model for Tanzania and Zambia and Maisonnave & Décaluwé [2010] for South-Africa directly model the choice between different skill levels. Both papers develop a recursive dynamic model where the endogenous skill choice of the labor force does not only depend on the wage differential but also on the level of public capital in education. They find that increasing public capital in education has moderate growth effects. Jung & Thorbecke [2003] find that the production structure of the economy, the initial labor force structure as well as unemployment in the benchmark and targeting of the new investments have strong impacts on the results.

This paper takes Jung & Thorbecke [2003] as a point of departure and adds a number of aspects to the model. Most importantly, we model the process of human capital formation (i.e. schooling) and the human capital accumulation *explicitly* instead of including only the outcome of the educational process (i.e. the skill choice). This requires disaggregating skilled labor into the number of (physical) workers and the amount of human capital they have accumulated. In addition, the inclusion of schooling also allows to account for the effects of increased human capital accumulation on child labor employment and family income from child labor.[1] Given that child labor is an important production factor in Tanzania as in other African countries, this adds further insights.

We find that in general the aggregate growth effect of higher enrollment rates is positive but small. The magnitude of the growth effect from increased schooling strongly depends on the availability not only of schooling facilities but also of teachers. If enrollment is increased mainly by raising the pupil-teacher ratio, we do not find a growth effect. In addition, we find that the availability of enough schools and teachers alone leads to a strong endogenous decrease in child labor even if the government fails to enforce enrollment. The expected future return to education is high enough that a majority of the households accept the foregone earnings from child labor and send their child to school, once the opportunity is there.

A substantial increase in enrollment is necessary if human capital accumulation is intended to grow faster than the population. Only a fraction of all enrolled children will really accumulate human capital due to non-passing and lower quality of teaching if the

[1] This aspect of educational policy is also mentioned by Maisonnave & Décaluwé [2010].

pupil-teacher ratio increases.

On the production side we see that in the first years after an increase in enrollment the availability of skilled labor outside the public sector stagnates due to the requirement of additional teachers. In addition, some export-oriented agricultural sectors are very sensitive to decreases in child labor supply and face strongly declining output if enrollment is increased. We find clear indications that capital and also land constrain the production effect from increased high-skilled labor supply.

The remainder of this paper is structured as follows: The next section gives an overview of the CGE literature in this specific field. Section 3 describes our model in detail, followed by a description of the data. In section 5 we present the scenarios we simulate. Results are summarized in section 6 which is followed by a conclusion.

5.2. CGE models on educational policy in Africa

Our study uses a recursive-dynamic economy-wide macro-economic model with a detailed educational sector to analyze increases in investment for education in a Sub-Saharan African country, namely Tanzania. There exist three other studies that use comparable models: Jung & Thorbecke [2003], Agenor *et al.* [2008] and Maisonnave & Décaluwé [2010]. We combine several features from these models and hence we briefly describe these models here with a focus on the educational component.

Jung & Thorbecke [2003] model an educational investment program in the two countries Zambia and Tanzania and compare the results. Their model is a neoclassical multisector recursive-dynamic CGE model comparable to the dynamic IFPRI model. Given their focus on the comparison of two countries, the model uses an aggregated production and household structure (three sectors, four households). The educational sector, however, is modeled in detail. They distinguish between unskilled, semi-skilled and skilled labor. The skill choice equation is derived outside the model. The decision whether to choose a higher level of schooling depends on the wage differential between the current skill level and the next skill level and the availability of educational institutions. The skill choice is made from one period to the next and labor supply is updated correspondingly. Their baseline path is characterized by a proportional growth in all skill classes (equal to population growth) and unskilled unemployment. Their policy scenario is an increase in the availability of schools by 15%. They find a positive but low GDP effect for both countries. Wage effects as well as effects on household incomes differ substantially between the two countries. This is attributed to differences in capital endowments and in the structure of unemployment between the countries.

Agenor *et al.* [2008] use a substantially more aggregated approach. Their model is a one-sector-one-household model leaving distributional and reallocation issues aside.

Educational reform is modeled in the nested production function. Public capital in education enters the composite *public education input* which is needed to transform *raw labor* into *educated labor* which is afterwards combined with public capital in health to form the *effective labor supply*. Hence, the model does not account for a skill choice by the households as it assumes that only educated labor is used in production and it does not distinguish between different skill levels. However, the decomposition of labor into the educational component and raw labor is an innovative way to measure the effects of investment in education. They conclude that a one-time permanent increase in aid allows the government to increase spending on health, education and infrastructure which leads to higher GDP growth and lower poverty. A distinction between the different spending purposes of aid is made in the text and also in the model, but the simulated shock affects all forms of public capital.

Maisonnave & Décaluwé [2010] model the impact of schooling in a recursive dynamic setup for South Africa. They follow up on Jung and Thorbecke's approach of a three-step schooling system but explicitly include the decision-making by pupils in the model. The decision whether a pupil will graduate, drop-out or repeat the skill-level again depends on the availability and quality of schools as well as on wages. Their model is very specifically tailored to the South African labor market as it accounts for ethnic differences in school attendance and unemployment. They find positive but moderate effects from better schooling quality on production and wages. At the disaggregate level, however, some sectors face declining production in reaction to an increase in the quality of schooling due to higher wages for all labor classes.

5.3. Model description

We use a model which is conceptually loosely based on the IFPRI recursive dynamic model as described in Thurlow [2004][2] and also used in Jung & Thorbecke [2003] but formulated in our study as a mixed complementarity problem (MCP)[3] and implemented with GAMS/MPSGE. A complete model code listing is included in the appendix.

We start from Jung & Thorbecke [2003], combine features of the models described above and add a number of major and minor features:

Most importantly, we adopt a decomposition of skilled labor into raw labor and human capital and combine this with a perspective on four different skill levels that are characterized by their human capital intensity. All different labor classes have a distinct production sector combining raw labor and human capital. Moreover, educational production, i.e. school attendance of children, is explicitly included in our model. Thus, we are able to include the decision problem between childrens' labor supply and school attendance but also the conflict between public service provision and teacher employment.

[2]See Arndt *et al.* [2010] and Thurlow & Wobst [2006] for applications based on this model.
[3]See Rutherford [1999] and Markusen [2004] for a detailed description of the modeling approach.

Jung & Thorbecke [2003] do not explicitly account for the financing of new schooling facilities, the increase in public capital in education is exogenous in their model. We directly model the increase in public capital as financed by aid, i.e. an external transfer to the government. Moreover, an improvement in education does not only require an increase in the availability of schools, but also higher public recurrent expenditure as it raises the demand for teachers. We therefore introduce the requirement for teachers in the production function for education and assume this spending component to be part of the government's budget.

In addition, as we directly model the production of education, we are also able to include education explicitly into households' demand function, thus the demand for education becomes endogenous in our model. The endogenous skill choice in Jung & Thorbecke [2003] is made from one period to the next. This neglects the fact that the lag between the increase in education facilities and the rising educated labor supply takes several years. We therefore include a longer lag here by disaggregating skilled labor into raw labor and years of schooling and assuming that a higher skilled worker requires more years of schooling. Over and above, in African developing countries the skill choice is not only dependent on the wage difference between unskilled and skilled labor. It also involves foregone family income from child labor as Maisonnave & Décaluwé [2010] point out. We have chosen a dataset which incorporates child labor. Thus, we include the endogenous choice between sending the child to school and sending it to work (mainly in agriculture) in some of our scenarios.

The datasets used in Jung & Thorbecke [2003] have been aggregated to a very high level of aggregation (3 sectors, 4 households) in order to be able to compare the two countries in the application. As the provision of additional education has large-scale impacts on the sectoral production structure as well as on distribution, we keep the disaggregated structure of our dataset, which means that our model includes 38 sectors and 13 production factors as well as 12 household types (disaggregated by region, education of household head and income). The production factors are mainly different labor types highly disaggregated with respect to their skills (child labor, unskilled adults, adults who have not finished primary school, not finished secondary school, secondary and higher educated), two types of capital, subsistence composite and land.[4] The data is for Tanzania in 2001.[5]

Some minor changes are made concerning the government sector, household consumption and production as well as elasticities and functional specifications. These are mainly required by the structure of the data. We additionally adopt a different model closure, in accordance with Thurlow [2004], holding world market prices and the external balance

[4] An overview of all abbreviations for households, factors and sectors used in the remainder of the paper is given in table 5.12 in the appendix.

[5] There exist few African datasets with the required disaggregation into skill classes and including child labor. The given dataset allows to compare our results with those from Jung & Thorbecke [2003] as well as with the effects of schooling projects that have been realised during the simulated period and the datasets are comparable as all are provided by IFPRI.

fixed and allowing investment to adjust to changes in savings.

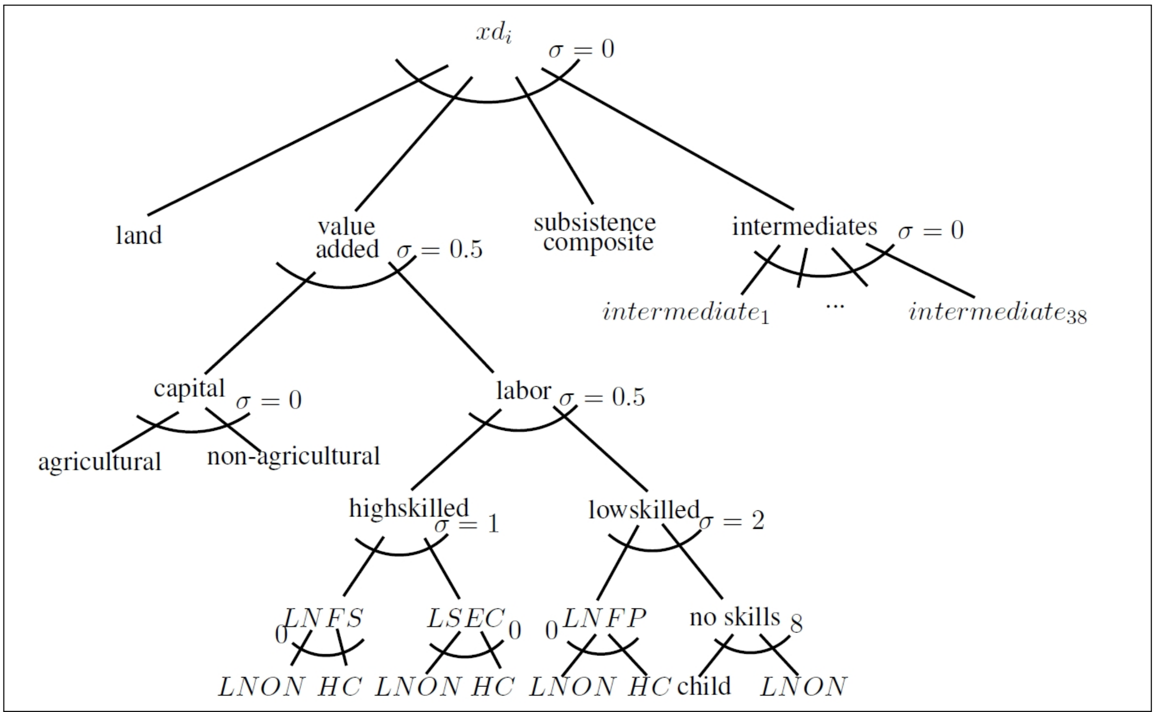
5.3.1. Within-period specification

Our model is a recursive-dynamic neoclassical CGE model with an Armington production structure. Hence, the agents in the economy optimize their behavior in each period given current prices, endowments and their preferences. Their decisions affect the evolution of the physical capital and human capital stock which is updated between periods. In general, agents in this kind of model display myopic behavior. However, we introduce some aspects of quasi-forward looking behavior in the schooling choices.

Production function

We use a 5-stage nested production function with a very detailed labor structure as shown in figure 5.1.

Figure 5.1.: Nested production function



Domestic production (xd) in each sector i is produced as a combination of intermediates, land, the subsistence composite[6] and value added. Value added is decomposed into capital and labor, where labor is a composite of high-skilled and lower skilled labor. We assume a Leontief structure for the top level nest and between agricultural and non-agricultural capital. Capital and labor are weakly substitutable ($\sigma = 0.5$) which is also true for the substitution between highskilled (LNFS, LSEC) and lowskilled (LNFP, LNON) labor. Labor of neighboring skill classes (LNFS and LSEC, LNFP and LNON) is

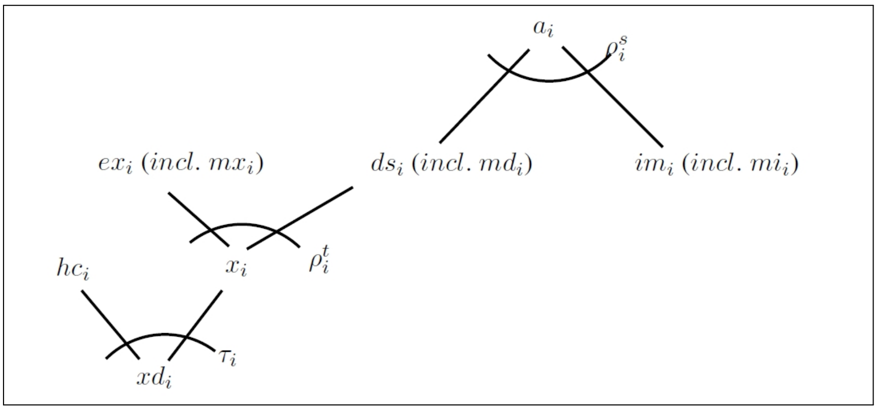
[6]This refers to the non-decomposable inputs of capital and different labor classes in subsistence farming.

highly substitutable. Child labor is one form of unskilled labor and highly substitutable with unskilled adults (LNON). Each skilled labor type (LNFP, LNFS, LSEC) is a specific Leontief combination of raw labor (LNON) and human capital (HC).

Domestic supply

Domestic production (see figure 5.2) may either be used directly as home consumption (hc_i) or be marketed (x_i) either on the export (ex_i) or on the domestic market (ds_i). Domestic market sales are imperfect substitutes for imported goods (im_i) as the so called Armington specification implies. Depending on the sales market a trade and transport margin is added to the value of production and imports (mx_i, md_i, mi_i).

Figure 5.2.: Sales markets



The sectoral Armington elasticities (τ_i, ρ_i^t and ρ_i^s) have been chosen in correspondence with other models in the literature and we explore their relevance in the sensitivity analysis.[7] The Armington elasticities are listed in table 5.14 in the appendix.

Demand

Households earn income from their endowment with labor, agricultural capital, physical enterprise capital, subsistence composite, land and human capital as well as from transfers and remittances. They use their income for consumption, direct tax payments, remittances, savings and education. Households endowment with human capital is described in more detail below.

Household preferences are modeled in a two-stage nested utility function. Consumption of goods is modeled in a Cobb-Douglas function. Demand for education depends positively on the income of the household, the current price of human capital, as a proxy for expected future return on human capital, and households initial demand for education, i.e. their endowment with children. The consumption nest and education are fairly imperfect substitutes ($s = 0.5$) in the households' utility top nest.

[7]See appendix for details.

$$U_h = U(\overset{+}{Cons},\ \overset{+}{Edu}) \tag{5.1}$$

The government earns income from indirect and direct taxes, import tariffs, foreign aid and public enterprises. It utilizes its income to provide public services, pay teachers, construct schools and for transfers to households and public savings.

Export demand for domestic products is perfectly elastic and adjusts to export supply. The rest of the world pays and receives remittances, transfers foreign aid and school capital to the government. Investment demand is driven by savings.

Human capital and education

We decompose skilled and semi-skilled labor into the content of raw labor and human capital by matching our Social Accounting dataset with the underlying Labor Force Survey such that the values from the Social Accounting Matrix (SAM) can be transformed into numbers of workers. We suppose that the remaining value of skilled and semi-skilled labor on top of the value of the (unskilled) raw worker is the value of the human capital the individual has accumulated. By matching the two datasets we find a non-linear relationship between the years of schooling an individual has completed and the value of his human capital (see table 5.1). This is in line with findings from the econometric literature which states that primary skills provide a higher return compared to secondary skills. Tanzania has a three-step schooling system with a primary school of eight years, 4 years of secondary school and two additional years of tertiary school. We classify 12 and more years as secondary and higher education and thus refer to these workers as high skilled workers in the following sections. Workers who have not finished secondary school are referred to as semi-skilled workers and those who have not finished primary school as low skilled workers. The decomposition and estimation procedure is described in section 5.4.2.

Table 5.1.: Estimated labor force decomposition, based on Thurlow & Wobst [2003].

Labor class	Approx. years of schooling	Estimated share of human capital in value of worker $(1-\theta)$	Share of total labor force	Share of labor income
Subsistence labor (FSUB)	< 2	0%	36.2%	45.8%
Child labor (LCHILD)	0	0%	8.6%	0.5%
No education (LNON)	< 2	0%	14.1 %	3.6%
Not finished primary school (LNFP)	2-7	25%	9.8%	8.2%
Not finished secondary school (LNFS)	8-11	30%	29%	28.4%
Secondary or higher education (LSEC)	12 +	95%	2.4%	13.6%

Based on these coefficients we calculated the endowment with workers and human capital for each household type. Labor supply (L) of every skill type (s) except from "child", "subsistence" and "no education" are then modeled explicitly in a production function using the input coefficients shown in table 5.1. Where human capital (HC) and physical worker (L_{non}) are of course complements meaning that each skill type has a Leontief production function combining the physical and the skill input. Skilled, semi-skilled and unskilled workers are then used in production as shown in figure 5.1.

$$L_s = \theta L_{non} + (1-\theta)HC \tag{5.2}$$

New human capital is produced by the education sector. Educational production (S_{edu}) requires children, teachers and schools. Depending on the policy scenario we define teachers and schools either as complements or very imperfect substitutes. In two possible cases teachers and schools are not strictly complements: Educational production could be expanded by only increasing the number of pupils and schools without increasing the number of teachers which means bigger classes or by increasing the number of teachers ($admin$) and pupils without increasing the number of schools which could be realized by double shifting in class rooms, as is commonly done in African schools.

$$S_{edu} = f(\overset{+}{children},\, \overset{+}{xd_{admin}},\, \overset{+}{schools},\, \overset{-}{p_{admin}},\, \overset{-}{w_{child}},\, \overset{+}{p_{edu}}) \tag{5.3}$$

Each child may either work or attend a school depending on the utility from education. This is modeled by introducing education into the households' demand functions and making demand for education dependent on the price of human capital (as a proxy for expected future return on human capital), the price of education itself and households' endowment with children. Consequently, if the price for human capital is high, households will demand more education and thus, more children will attend school instead of working.

$$D_h^{edu} = D(\overset{+}{children_h}, \overset{-}{p_{edu}}, \overset{+}{p_{hc}}) \tag{5.4}$$

This will also have an increasing effect on childrens' wages (w_{child}) as the number of child workers decreases. The indirect effect here is that the opportunity costs of sending a child to school grow. However, educational production will also expand if the availability of schools or teachers rises given the Leontief structure of the educational production function. In this case, however, the price of education will fall if there is excess production relative to demand by households. We also include scenarios where we enforce a 100% enrollment rate by exogenously setting labor demand for children to zero, which represents an effective ban on child labor. In this case the opportunity cost of sending a child to school is zero as the outside option of working is not given. Households' preferences will still be linked to the price of human capital. Hence, if the price of human capital is low, households' utility from enforced schooling is low. The opportunity cost of sending a child to school is captured in the model by the wage for children. The utility from education is captured by the equilibrium price for education in household demand.

Given that teachers (i.e. public services in the dataset) are modeled as an input in education, a higher provision of education will lead to rising demand for semi-skilled and skilled workers. Hence, as long as the schooling process still takes place it creates a pressure on the market for skilled workers and leads to higher relative wages for high-skilled. Once the schooling from previous periods leads to growing supply of human capital, this bottleneck could be eliminated and the relative wage premium is reduced or disappears.

Model closure

The factor markets are closed by flexible wages that adjust to ensure that the exogenously fixed factor supply is employed. We do not include unemployment as subsistence agriculture and home consumption is included as productive activity and thus official registered unemployment is partly included as subsistence labor in our data.

External markets are cleared by flexible demand and supply on world markets and fixed world market prices as well as a fixed current account balance. All transfers within the country and between the country and the rest of the world are held constant. Investment adjusts to equal savings. Savings are determined by a fixed marginal propensity to save for each household. Hence, savings and investment demand grow with income.

5.3.2. Between-period specification

From one period to the next we update a number of variables, namely labor supply, physical and human capital stock and productivity.

Labor force dynamics

We assume that the supply of unskilled labor and the subsistence composite grows by 2.7% per year while the supply of children grows by 2.75% per year. Both numbers have been calculated based on the real development of the working age population and population aged 10-14 in the years 2001-2010.

The development of skilled labor supply of any skill class, however, is endogenous in our model (unlike in Jung & Thorbecke [2003] who assume a proportional growth of all skill classes in their baseline) and depends on educational production in former years as well as demand for the different skill levels. Human capital accumulation is explained below. New labor is distributed to the household endowments proportionally to their initial endowment.

Human capital accumulation

The human capital stock grows if a child spends a year at school and does not have to repeat the class. It passes the final examination and either leaves the school, goes on to the next class or graduates. We have calculated the average pass rates from the educational transition matrix for Tanzania in Wobst & Arndt [2004] and are thus able to calculate the number of successful pupils that have accumulated an additional unit of human capital. We discount this number by the pupil-teacher-ratio relative to the base year as we know from recent experiences in the two educational programs in Tanzania that a higher pupil-teacher ratio has led to lower pass-rates.[8] New human capital is distributed to the households based on their endowment with children.

Capital stock dynamics

The initial capital stocks in the base year have been calculated based on capital earnings reported in the SAM and interest and depreciation rates as found in Central Bank statistics and econometric studies. We update the capital stock by depreciating current capital by 6.5% and adding new investment as found in the model and adjusting this with an exogenous productivity parameter in order to match actual rates of capital formation. The new capital stock is allocated to the households proportionally to their initial endowment with capital.

School provision development

In the baseline scenario we assume a moderate growth in the availability of both public capital in education and educational staff. The baseline growth rates of these two variables have been calculated from the development of the number of schools and the number of teachers in the 1990s. It was not possible to use the real development in the simulation period as Tanzania realized two large scale education projects during this period. Hence, we use the 1990s as a reference period. In our policy counterfactuals we raise either only the public investment in schools or both capital and recurrent public spending on education and investigate the differences in the results.

Productivity growth

As in most recursive-dynamic CGE models we assume a baseline growth path for total factor productivity. In accordance with many CGE and econometric models as well as with Jung & Thorbecke [2003] we chose total factor productivity in the baseline scenario in a way that leads to an approximate replication of the past GDP growth rates. This baseline productivity growth, which results at 5% in our model, as well as the adjustment of the capital stock is common for all scenarios and hence does not affect any conclusion about the different educational policies we simulate.

5.4. Data

5.4.1. Data sources and SAM aggregation

We use the IFPRI SAM for Tanzania for 2001 as described in Thurlow & Wobst [2003]. We chose Tanzania for several reasons: First, Tanzania and Zambia are natural candidates for our study as this allows to at least partly compare our results with those from

[8] See The World Bank [2005] and The World Bank [2011].

Jung & Thorbecke [2003]. Among these two, Tanzania was chosen because Tanzania has realized two large scale educational projects since the base year of the most recent SAM, hence we can compare our results with the experiences in reality. Moreover, the IFPRI Tanzania SAM is very rich in terms of educational disaggregation of the labor force and it provides information on child labor, both because it is linked to the very detailed Labor Force Survey 2000/2001. This degree of disaggregation was necessary in order to match our modeling of human capital production and accumulation. The availability of a Labor Force Survey for the same year provided important additional information and allowed to disaggregate skilled and semi-skilled labor into the two components raw labor and human capital appropriately. In addition, Tanzanian school statistics are also quite complete and provide a time series dimension. This information was helpful to find appropriate proxies for public capital in education, the baseline growth rate of schools and teachers and the total number of pupils between ages 10 and 14.

We aggregate the data slightly in the sectoral dimension. Instead of the original 43 sectors, we retain 38 sectors. We keep the full detail of household and factor disaggregation, we only drop the gender-disaggregation in labor classes for reasons of simplicity and due to a lack of information on the gender of child labor. Table 5.11 in the appendix gives an overview of the household and labor class definitions.

Additional data on the labor force, population (population growth, young population, working age population, regional distribution of children and adults) and the schooling system (number of teachers, number of schools, enrollment by age group, enrollment by region) has been taken from the 2000/2001 Tanzania Labor Force Survey, the 2000/2001 Census and several editions of the National Basic Education Statistics (BSE). In addition, we have used Central Bank statistics to calculate the interest rate.

From schooling statistics we estimate the number of pupils that are between 10 and 14 years old (i.e. have the outside option of working by the definition of our dataset) and the enrollment rates in these age groups for rural and urban regions. We could thus approximate the additional endowment with non-working children for the different households and define these as pupils.

Descriptive tables on the sectoral factor and trade intensities, households' income and spending structure are included in the appendix.

5.4.2. Skilled labor disaggregation

Social Accounting Matrices commonly report values for the inputs in production not the quantities and prices separately. In CGE applications the convention is usually that the initial prices are all set to unity such that values and quantities are equal. Thus, from the SAM information on the wage premium for human capital cannot be retrieved, however we follow a modeling procedure which discriminates between the number of (physical) workers and the value of their human capital. Hence, we had to combine the SAM data with other data in order to find out the number of skilled workers instead of their value and this has to be done for all different skill classes.

Fortunately the IFPRI SAM uses labor force data from the Labour Force Survey 2000/2001[9] and thus a mapping of the number of workers and the value of these workers is available. [See Thurlow & Wobst, 2003, p.27] Please note, this mapping is only available for the whole labor force not on a sectoral basis. Hence we are only able to make an average decomposition not a sector-specific decomposition.

We decompose the values from the SAM into the value of the physical, unskilled workers and the value of their human capital. We first calculate the average wage of an unskilled worker (w_{LNON} as the sum of earnings from unskilled labor in all sectors i (D_i^{LNON}) from the SAM divided by the number of such workers in the Labor Force Survey (n_{LNON}):

$$w_{LNON} = \frac{\sum_i D_i^{LNON}(SAM)}{n_{LNON}(LFS)} \tag{5.5}$$

For each skilled labor class (s) we then calculate the implicit value of the physical workers in this skill class over all sectors ($\sum_i D_{i,s}^{LNON}$), by multiplying the number of such workers from the LFS (n_s) with the wage for unskilled workers:

$$\sum_i D_{i,s}^{LNON} = n_s(LFS) \cdot w_{LNON} \tag{5.6}$$

Hence, the value of human capital for each skill class (s) in all sectors (i) ($D_{i,s}^{HC}$)is retrieved as the difference between the earnings of these workers in the SAM ($\sum_i D_i^{L_s}$) and the implicit value of their physical labor force.

$$\sum_i D_{i,s}^{HC} = \sum_i D_i^{L_s} - \sum_i D_{i,s}^{LNON} \tag{5.7}$$

Having retrieved the aggregate numbers for the implicit values of workers and human capital for each skill class (s), we are now able to calculate the shares reported in table 5.1. These shares are used to calculate the endowments with human capital and unskilled workers for each household type h and for the calibration of the production functions for skilled workers of the different skill levels. Thus, we have finally decomposed demand and supply of labor of any skill class into unskilled workers and a certain amount of human capital.

5.5. Baseline assumptions and counterfactuals

In the model briefly described above we simulate different scenarios which all represent educational policy programs. These are briefly summarized in table 5.2.

[9]Tanzanian National Bureau of Statistics (2002).

Table 5.2.: Scenario specification

Variable	**Scenario**				
	0	1	2	3	4
School provision	grows with population growth rate (n)	grows by 52.2% in 2002 and afterwards with rate n	grows with population growth rate (n)	grows with $n+2$ in 2002 & 2003, $n+1$ in 2004, $n+5$ in 2005 and 2006 and n from 2007 onwards	grows by 52.2% in 2002 and afterwards with rate n
Number of teachers	grows with population growth rate (n)	endogenous	endogenous	endogenous	endogenous
Pupil-teacher ratio	endogenous	constant	endogenous	endogenous	endogenous
Child labor	Possible	Prohibited	Prohibited	Possible	Possible

In the first and second counterfactual we simulate a policy where the government enforces a 100% enrollment rate, i.e., we do not allow children to be employed. However, only in the first counterfactual we provide the required schooling resources to hold the pupil-school ratio and the pupil-teacher-ratio constant. This means a massive increase in the availability of schools (by 52.2%) and in the employment of teaching staff in the first simulation period. Afterwards, schooling investment and educational staff grow with the same growth rate as in the baseline scenario.

In the second counterfactual we also prohibit child labor but the government continues to increase schools and teachers only with the baseline growth rate. This means that the pupil-teacher and pupil-school ratio increase and probably some children will not find a place in a school but are not allowed to work, either.

In the third scenario we simulate a rather modest investment scenario with a continuous increase in public investment over the years which is based on the two projects that were realized in Tanzania during the simulation period. We simulate the following path for the number of schools: In 2002 and 2003, the number of schools increases by 2% plus the baseline growth. In 2004, an additional 1% is added and in 2005 and 2006 5% on top of the baseline growth rate. Up from 2007, schools grow with the baseline growth rate. We assume the number of teachers to grow in accordance with the demand for teachers from the educational sector. However, we allow childrens' work as an outside option. In addition, we assume that the productivity of skilled labor grows by 10% up from 2005 due to increased quality in education.

In the forth counterfactual we assume that the government increases public investment by 52.2% like in the first scenario which means that now each child would have a place in school. We assume teaching staff employment to grow endogenously. We allow for a higher pupil-teacher ratio and hold the pupil-school ratio constant. Child labor is allowed as an outside option.

It is assumed across all scenarios that the public investment (building of schools) is financed by aid whereas the additional teachers have to be financed from the governmental budget. Hence, educational policy is detrimental to other public service provision. We hold the population and productivity growth rates constant across the different counterfactuals.

5.6. Simulation results and sensitivity analysis

5.6.1. Results

Table 5.3 shows the development of the educational inputs and production in the different scenarios. The public capital in schooling is always set exogenously whereas the number of teachers is only set exogenously in scenario 1 (implicitly by holding the pupil-teacher ratio constant). The number of pupils and educational production are determined in the model following households' demand for education and the working possibility for children. The human capital stock results endogenously from educational production and the pupil-teacher ratio in previous periods.

Table 5.3.: Educational variables

Variable	Scenario	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Public capital in schooling	**0**	1.0000	1.0270	1.0547	1.0832	1.1125	1.1425	1.1733	1.2050	1.2376	1.2710
	1	1.0000	1.5222	1.5641	1.6071	1.6513	1.6967	1.7434	1.7913	1.8406	1.8912
	2	1.0000	1.0270	1.0547	1.0832	1.1125	1.1425	1.1733	1.2050	1.2376	1.2710
	3	1.0000	1.0481	1.0984	1.1399	1.2298	1.3268	1.3633	1.4008	1.4393	1.4789
	4	1.0000	1.5222	1.5641	1.6071	1.6513	1.6967	1.7434	1.7913	1.8406	1.8912
Number of pupils	**0**	1.0000	1.0402	1.0981	1.1592	1.2224	1.2880	1.3562	1.4274	1.5017	1.5796
	1	1.0000	1.3185	1.5137	1.5702	1.6239	1.6797	1.7376	1.7977	1.8604	1.9259
	2	1.0000	1.5747	1.6747	1.7809	1.8940	2.0142	2.1420	2.2779	2.4225	2.5762
	3	1.0000	1.0374	1.0926	1.1446	1.2659	1.3712	1.4449	1.5057	1.5682	1.6330
	4	1.0000	1.3544	1.4943	1.5687	1.6467	1.7280	1.8122	1.8996	1.9904	2.0850
Number of teachers	**0**	1.0000	1.0160	1.0486	1.0848	1.1228	1.1627	1.2044	1.2480	1.2937	1.3413
	1	1.0000	1.3185	1.5137	1.5702	1.6239	1.6797	1.7376	1.7977	1.8604	1.9259
	2	1.0000	1.0270	1.0547	1.0832	1.1125	1.1425	1.1733	1.2050	1.2376	1.2710
	3	1.0000	1.0374	1.0926	1.1446	1.2148	1.3061	1.3651	1.4108	1.4578	1.5066
	4	1.0000	1.3702	1.5005	1.5413	1.5830	1.6276	1.6744	1.7235	1.7748	1.8285
Educational production	**0**	1.0000	1.0270	1.0548	1.0834	1.1128	1.1430	1.1740	1.2058	1.2385	1.2721
	1	1.0000	1.5189	1.5635	1.6066	1.6510	1.6965	1.7433	1.7914	1.8408	1.8916
	2	1.0000	1.0277	1.0555	1.0840	1.1133	1.1434	1.1742	1.2060	1.2385	1.2720
	3	1.0000	1.0479	1.0983	1.1400	1.2298	1.3268	1.3635	1.4011	1.4397	1.4794
	4	1.0000	1.5191	1.5632	1.6063	1.6506	1.6962	1.7429	1.7910	1.8404	1.8912
Pupil-teacher ratio	**0**	1.0000	1.0000	1.0239	1.0472	1.0686	1.0887	1.1078	1.1261	1.1437	1.1608
	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	1.0000	1.0000	1.5333	1.5878	1.6441	1.7025	1.7630	1.8255	1.8904	1.9575
	3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0421	1.0498	1.0584	1.0672	1.0757
	4	1.0000	1.0000	0.9885	0.9959	1.0178	1.0403	1.0617	1.0823	1.1022	1.1215
Human capital stock	**0**	1.0000	1.0211	1.0426	1.0648	1.0877	1.1114	1.1360	1.1615	1.1878	1.2152
	1	1.0000	1.0211	1.0490	1.0810	1.1142	1.1485	1.1840	1.2207	1.2587	1.2980
	2	1.0000	1.0211	1.0428	1.0651	1.0880	1.1115	1.1357	1.1605	1.1859	1.2121
	3	1.0000	1.0211	1.0431	1.0661	1.0923	1.1201	1.1499	1.1811	1.2133	1.2466
	4	1.0000	1.0211	1.0501	1.0818	1.1144	1.1478	1.1822	1.2176	1.2540	1.2916

It is important to mention that the assumed size of public investment differs quite substantially across the scenarios: It is visible in the first section of table 5.3 that scenario

3 which is based on the projects realized in Tanzania has a much lower investment, i.e. lower school provision, compared to the high investment in scenarios 1 and 4. However, the projects have not done most of the investment in the first year but the investment is splitted in two projects and grows gradually.

When children are not allowed to work by assumption (scenarios 1 and 2), the number of pupils at the end of the simulation period is about 89% higher then in 2001 and about 60% higher compared to simply continuing with current enrollment (scenario 0). Even if public investment is high enough to provide additional places in schools for every child currently working, if the pupil-teacher ratio is held constant, the endogenous employment of teachers is not sufficient to allow every child to go to school in scenario 1. In scenario 2 all children are enrolled but at current school and teacher provision this would lead to about 50% more pupils per teacher.

Without additional investment and additional teachers (2), 100% enrollment does not increase educational production significantly compared to the baseline-levels. On the other hand, if there is a sufficient school provision with enough teachers being employed, even if the outside option of working is retained (4) the majority of children is endogenously sent to school and educational production as well as human capital accumulation is nearly as high as with enforced mandatory schooling.

The effect on the stock of human capital, however, is modest even in the high investment scenarios 1 and 4. This is mainly due to the fact that pass rates are on average at only 75% and that human capital accumulation is assumed to be slower if the pupil teacher ratio rises. In this aspect the reality-based scenario 3 lies in between the *business as usual* scenario 0 and the high investment provision in scenario 2.

Table 5.4.: Results: Macroeconomic aggregates (benchmark = 1)

Variable	**Scenario**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
GDP	**0**	1.0000	1.0419	1.0862	1.1332	1.1833	1.2366	1.2934	1.3539	1.4185	1.4873
	1	1.0000	1.0385	1.0839	1.1328	1.1847	1.2400	1.2987	1.3611	1.4275	1.4981
	2	1.0000	1.0385	1.0826	1.1293	1.1790	1.2319	1.2882	1.3482	1.4121	1.4803
	3	1.0000	1.0419	1.0863	1.1336	1.1836	1.2370	1.2944	1.3556	1.4208	1.4902
	4	1.0000	1.0399	1.0853	1.1344	1.1865	1.2418	1.3005	1.3630	1.4294	1.5000
Welfare	**0**	1.0000	1.0413	1.0839	1.1280	1.1744	1.2232	1.2747	1.3290	1.3862	1.4466
	1	1.0000	1.0417	1.0840	1.1294	1.1782	1.2296	1.2839	1.3413	1.4019	1.4659
	2	1.0000	1.0393	1.0817	1.1253	1.1712	1.2195	1.2702	1.3235	1.3795	1.4385
	3	1.0000	1.0418	1.0847	1.1287	1.1794	1.2305	1.2817	1.3365	1.3945	1.4558
	4	1.0000	1.0479	1.0891	1.1348	1.1836	1.2347	1.2887	1.3457	1.4058	1.4694
GDP growth rate (in%)	**0**		4.1909	4.2484	4.3291	4.4184	4.5067	4.5941	4.6807	4.7664	4.8516
	1		3.8514	4.3734	4.5048	4.5894	4.6626	4.7350	4.8064	4.8771	4.9473
	2		3.8514	4.2415	4.3157	4.4027	4.4877	4.5724	4.6566	4.7404	4.8241
	3		4.1927	4.2596	4.3521	4.4079	4.5198	4.6331	4.7274	4.8105	4.8902
	4		3.9913	4.3665	4.5216	4.5934	4.6605	4.7309	4.8009	4.8707	4.9403
GDP/ Capita	**0**	1.0000	1.0149	1.0314	1.0499	1.0708	1.0940	1.1200	1.1488	1.1808	1.2162
	1	1.0000	1.0115	1.0292	1.0495	1.0722	1.0974	1.1253	1.1560	1.1898	1.2270
	2	1.0000	1.0115	1.0278	1.0460	1.0665	1.0893	1.1148	1.1431	1.1745	1.2091
	3	1.0000	1.0149	1.0316	1.0503	1.0710	1.0945	1.1209	1.1504	1.1831	1.2191
	4	1.0000	1.0129	1.0306	1.0511	1.0740	1.0992	1.1271	1.1579	1.1917	1.2289

In general, we see a slight welfare and GDP increase compared to the baserun in any of the scenarios with higher investment. However, the welfare effect as well as the production effect are rather small compared to the massive investment simulated. It is highest in those scenarios where we have a large increase in school provision whereas it is smaller if school availability lacks behind the number of pupils. The welfare effect is highest in scenario 4 with high schooling provision and endogenous selection into school attendance.

In the case where child labor is prohibited but schooling is not sufficiently provided (2), we see a strong increase in the pupil-teacher ratio but nearly no effect on welfare and GDP compared to the baseline. This is because educational production and human capital accumulation are nearly unchanged compared to the baseline as pupils do not find a sufficient schooling environment to learn and accumulate human capital while they do not have the alternative to work and thus do not produce something and earn income for their households.

Annual GDP growth rates show a much more heterogeneous picture than GDP and reveal that the two scenarios with very high schooling investment (1 and 4) produce lower growth rates in the first period, followed by a growth boost when the additional human capital enters the labor market and remaining at higher growth rates afterwards, whereas the project scenario (3) leads to a slow but steady increase in GDP growth in 2002 to 2009.

Table 5.5.: Results: Factor prices in 2010, base year level = 1

Scenario	**FSUB**	**LCHILD**	**LNON**	**LNFP**	**LNFS**	**LSEC**	**CAPAG**	**CAPNAG**	**LAND**
0	0.875	0.500	0.470	0.943	1.199	1.236	0.819	0.944	1.666
1	0.848	0.000	0.436	0.824	1.034	1.065	0.730	0.981	2.277
2	0.884	0.051	0.487	0.980	1.248	1.286	0.861	0.934	1.468
3	0.867	0.485	0.452	0.892	1.130	1.164	0.778	0.958	1.925
4	0.850	0.521	0.447	0.816	1.016	1.044	0.716	0.984	2.302

A more disaggregated perspective on factor supply (table 5.6) shows that, if skill choice is modeled endogenously most of the human capital accumulated will be used for semi-skilled and high-skilled labor provision, the relative provision of labor with only primary skills decreases.

Factor prices (table 5.5) reveal that rents on capital increase relative to the wages of unskilled labor but not to the level of high skilled wages. This is in reaction to the relative growth of labor in comparison to capital and land in combination with the assumed increase in capital productivity. Most importantly, land rents increase relative to returns to all other factors. This shows that land acts as a rationing factor for an overall production response given its fixed supply and non-substitutability with other production factors. This supports the arguments by other authors such as Schultz [1999] and Pritchett [2001] that schooling investment does not provide high social returns because labor is not equipped with enough complementary resources to be highly productive. In our case land evolves as the rationing factor. However, for other countries or with lower capital productivity capital might as well limit the productivity of additional skilled workers.

Child wages reflect the alternative costs of schooling. If children are not allowed to work (scenarios 1 and 2), the opportunity cost of sending the children to school is very low or even zero (in scenario 1). If schooling provision and demand for education rises, but the outside option of working is in place as well, the opportunity cost of going to school is positive and childrens' wages remain at a comparable level to unskilled adults' wages.

Table 5.6 summarizes the employment effects of the different policies. Unskilled labor employment grows faster than skilled employment due to lagged and costly provision of high skilled labor. Interestingly, primary skilled labor employment shows a non-monotonic development in most scenarios: during the first years a slight increase and later on a decrease. The main reason for this phenomenon is that secondary schooling requires primary schooling and thus in the first years additional primary skilled workers enter the labor market.

While an above-average proportion of the new semi skilled labor works outside the public sector, the opposite is true for high skilled labor. High skilled workers outside the public sector grow slower than the overall employment of these workers. Hence, indeed we find a diverting effect from other sectors to the public sector due to increased demand for teachers.

A further important and very positive result is that, even if child labor is not prohibited effectively, a sufficient school provision (scenario 4) reduces childrens' (endogenous) employment by 50% compared to the baseline case in 2010. However, even in the high investment scenarios 1 and 4, the ratio of skilled to unskilled labor decreases over time as human capital accumulation is slower than population growth.

At the sectoral level we find that not all sectors benefit from the general higher provision of labor. This mainly concerns export oriented agricultural sectors (coffee, cotton, cashew nuts, sugar and the trade sector itself). These seem to be very sensitive to any change in the structure of factor supply mainly due to their specific combination of land intensity and rather high skilled labor demand compared to domestically used agriculture. Hence, higher land rent and growing demand for high skilled labor in education hit these sectors twice, while a higher supply of children and unskilled labor is not beneficial to them.

Table 5.6.: Results: Employment (benchmark = 1)

Factor category	Scenario	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Subsistence composite	**0**	1.000	1.063	1.130	1.201	1.277	1.357	1.442	1.533	1.630	1.732
	1	1.000	1.063	1.130	1.201	1.277	1.357	1.442	1.533	1.630	1.732
	2	1.000	1.063	1.130	1.201	1.277	1.357	1.442	1.533	1.630	1.732
	3	1.000	1.063	1.130	1.201	1.277	1.357	1.442	1.533	1.630	1.732
	4	1.000	1.063	1.130	1.201	1.277	1.357	1.442	1.533	1.630	1.732
Child labor	**0**	1.000	1.112	1.199	1.293	1.397	1.510	1.634	1.769	1.915	2.073
	1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3	1.000	1.118	1.211	1.324	1.306	1.337	1.450	1.606	1.777	1.962
	4	1.000	0.458	0.375	0.441	0.514	0.595	0.686	0.787	0.899	1.022
Unskilled labor	**0**	1.000	1.196	1.414	1.648	1.899	2.168	2.456	2.764	3.092	3.442
	1	1.000	1.199	1.400	1.607	1.831	2.071	2.331	2.609	2.908	3.228
	2	1.000	1.200	1.415	1.647	1.897	2.164	2.451	2.759	3.088	3.439
	3	1.000	1.196	1.413	1.645	1.886	2.148	2.429	2.729	3.050	3.393
	4	1.000	1.182	1.369	1.577	1.804	2.050	2.315	2.599	2.905	3.233
Labor - not finished primary school	**0**	1.000	1.005	1.001	0.995	0.987	0.978	0.968	0.958	0.946	0.934
	1	1.000	1.002	1.004	1.008	1.010	1.011	1.010	1.008	1.006	1.002
	2	1.000	1.001	1.000	0.996	0.990	0.984	0.976	0.967	0.957	0.946
	3	1.000	1.005	1.001	0.995	0.995	0.990	0.982	0.973	0.962	0.951
	4	1.000	1.018	1.033	1.038	1.037	1.034	1.029	1.024	1.017	1.009
Labor - not finished secondary school	**0**	1.000	1.021	1.045	1.069	1.094	1.120	1.146	1.174	1.202	1.231
	1	1.000	1.019	1.047	1.078	1.111	1.145	1.180	1.216	1.253	1.291
	2	1.000	1.019	1.042	1.067	1.092	1.117	1.144	1.170	1.198	1.225
	3	1.000	1.022	1.045	1.070	1.099	1.127	1.156	1.185	1.216	1.247
	4	1.000	1.029	1.056	1.086	1.117	1.150	1.184	1.218	1.254	1.290
Labor - secondary and higher educated	**0**	1.000	1.027	1.054	1.083	1.114	1.145	1.179	1.214	1.252	1.291
	1	1.000	1.032	1.071	1.114	1.160	1.209	1.259	1.312	1.368	1.426
	2	1.000	1.033	1.061	1.089	1.118	1.149	1.181	1.215	1.250	1.287
	3	1.000	1.026	1.055	1.086	1.108	1.141	1.181	1.223	1.266	1.312
	4	1.000	1.006	1.045	1.091	1.138	1.187	1.238	1.291	1.346	1.403
Agricultural capital	**0**	1.000	1.036	1.074	1.116	1.160	1.208	1.260	1.316	1.377	1.442
	1	1.000	1.036	1.074	1.116	1.160	1.208	1.259	1.315	1.374	1.439
	2	1.000	1.036	1.074	1.116	1.160	1.208	1.260	1.316	1.376	1.442
	3	1.000	1.036	1.074	1.116	1.160	1.208	1.260	1.315	1.375	1.440
	4	1.000	1.036	1.074	1.116	1.160	1.208	1.260	1.315	1.375	1.439
Non-agricultural capital	**0**	1.000	1.036	1.074	1.116	1.160	1.208	1.260	1.316	1.376	1.441
	1	1.000	1.036	1.074	1.115	1.160	1.207	1.259	1.314	1.374	1.438
	2	1.000	1.036	1.074	1.115	1.160	1.208	1.260	1.315	1.376	1.441
	3	1.000	1.036	1.074	1.116	1.160	1.208	1.259	1.315	1.375	1.439
	4	1.000	1.036	1.074	1.116	1.160	1.208	1.259	1.315	1.374	1.439
Land	**0**	1.000	1.035	1.071	1.109	1.148	1.188	1.229	1.272	1.317	1.363
	1	1.000	1.035	1.071	1.109	1.148	1.188	1.229	1.272	1.317	1.363
	2	1.000	1.035	1.071	1.109	1.148	1.188	1.229	1.272	1.317	1.363
	3	1.000	1.035	1.071	1.109	1.148	1.188	1.229	1.272	1.317	1.363
	4	1.000	1.035	1.071	1.109	1.148	1.188	1.229	1.272	1.317	1.363

Non-agricultural sectors are generally less sensitive to changes in schooling provision compared to agricultural sectors. In agriculture and food processing we find significant differences between the scenarios. Most agricultural products, as well as hunting, forestry and fishing, experience an additional production boom in scenarios 1 and 4, whereas the opposite is true for maize, other crops and other staple food which are better off in the baseline without additional schooling. These are the main staple food sectors that suffer from the relative scarcity of land.

From a distributional perspective we see that investments in the educational system are clearly poverty reducing and lead to a more even income distribution (see table 5.7). Rural households benefit because land rents increase and thus they earn more. Households with a high-skilled head are better off in the baseline scenario and in scenario 2,

Table 5.7.: Results: Household income, base year = 1

Household group	**Sce-nario**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
rural, below food poverty line	**0**	1.000	1.038	1.081	1.127	1.176	1.229	1.285	1.346	1.411	1.481
	1	1.000	1.026	1.076	1.125	1.178	1.234	1.293	1.356	1.422	1.492
	2	1.000	1.031	1.076	1.122	1.171	1.224	1.282	1.343	1.409	1.480
	3	1.000	1.037	1.080	1.127	1.182	1.234	1.293	1.354	1.420	1.490
	4	1.000	1.036	1.083	1.131	1.183	1.238	1.297	1.359	1.425	1.495
rural, between food and basic needs line	**0**	1.000	1.036	1.077	1.122	1.170	1.221	1.276	1.335	1.399	1.467
	1	1.000	1.025	1.073	1.121	1.171	1.225	1.282	1.342	1.407	1.474
	2	1.000	1.030	1.073	1.118	1.166	1.218	1.273	1.333	1.398	1.468
	3	1.000	1.035	1.077	1.122	1.175	1.225	1.282	1.342	1.405	1.474
	4	1.000	1.033	1.079	1.125	1.175	1.228	1.285	1.345	1.409	1.476
rural, uneducated	**0**	1.000	1.037	1.083	1.133	1.189	1.249	1.315	1.387	1.465	1.549
	1	1.000	1.004	1.063	1.121	1.184	1.251	1.322	1.398	1.479	1.565
	2	1.000	1.011	1.062	1.114	1.170	1.232	1.299	1.372	1.451	1.537
	3	1.000	1.036	1.082	1.134	1.202	1.262	1.331	1.403	1.482	1.567
	4	1.000	1.041	1.096	1.150	1.210	1.274	1.343	1.417	1.496	1.580
rural, not finished primary school	**0**	1.000	1.034	1.074	1.117	1.164	1.214	1.268	1.325	1.388	1.454
	1	1.000	1.022	1.068	1.110	1.157	1.206	1.258	1.313	1.372	1.435
	2	1.000	1.028	1.070	1.114	1.161	1.212	1.267	1.326	1.390	1.459
	3	1.000	1.033	1.073	1.117	1.164	1.212	1.267	1.324	1.385	1.451
	4	1.000	1.031	1.072	1.114	1.160	1.208	1.260	1.316	1.375	1.438
rural, not finished secondary school	**0**	1.000	1.032	1.068	1.106	1.146	1.190	1.236	1.285	1.338	1.394
	1	1.000	1.026	1.065	1.103	1.143	1.186	1.231	1.280	1.332	1.387
	2	1.000	1.030	1.067	1.105	1.145	1.189	1.235	1.285	1.339	1.396
	3	1.000	1.031	1.067	1.106	1.146	1.189	1.236	1.285	1.337	1.393
	4	1.000	1.031	1.067	1.103	1.144	1.187	1.232	1.281	1.333	1.388
rural, secondary or higher educated	**0**	1.000	1.032	1.065	1.097	1.131	1.166	1.202	1.241	1.281	1.324
	1	1.000	1.039	1.068	1.092	1.119	1.148	1.178	1.210	1.245	1.282
	2	1.000	1.042	1.073	1.105	1.138	1.174	1.211	1.250	1.292	1.336
	3	1.000	1.032	1.064	1.096	1.120	1.154	1.190	1.227	1.265	1.307
	4	1.000	1.026	1.052	1.078	1.107	1.137	1.169	1.203	1.239	1.277
urban, below food poverty line	**0**	1.000	1.030	1.063	1.098	1.136	1.175	1.218	1.263	1.311	1.362
	1	1.000	1.029	1.063	1.099	1.138	1.179	1.223	1.270	1.319	1.373
	2	1.000	1.030	1.063	1.098	1.135	1.175	1.217	1.262	1.310	1.361
	3	1.000	1.030	1.063	1.098	1.138	1.177	1.220	1.266	1.315	1.367
	4	1.000	1.033	1.066	1.101	1.140	1.181	1.225	1.272	1.321	1.374
urban, between food and basic needs line	**0**	1.000	1.038	1.079	1.123	1.170	1.221	1.275	1.333	1.395	1.462
	1	1.000	1.025	1.072	1.120	1.172	1.226	1.285	1.347	1.413	1.484
	2	1.000	1.027	1.070	1.114	1.162	1.212	1.266	1.324	1.386	1.453
	3	1.000	1.038	1.079	1.124	1.179	1.230	1.285	1.344	1.408	1.475
	4	1.000	1.044	1.087	1.133	1.184	1.237	1.295	1.356	1.421	1.491
urban, uneducated	**0**	1.000	1.027	1.059	1.094	1.133	1.174	1.220	1.269	1.322	1.379
	1	1.000	1.011	1.048	1.089	1.132	1.179	1.230	1.284	1.342	1.403
	2	1.000	1.013	1.046	1.082	1.120	1.162	1.207	1.256	1.309	1.366
	3	1.000	1.027	1.059	1.094	1.141	1.184	1.231	1.281	1.336	1.394
	4	1.000	1.037	1.073	1.111	1.153	1.198	1.247	1.300	1.356	1.417
urban, not finished primary school	**0**	1.000	1.025	1.055	1.087	1.122	1.159	1.200	1.243	1.289	1.338
	1	1.000	1.022	1.053	1.082	1.114	1.148	1.185	1.225	1.267	1.313
	2	1.000	1.025	1.055	1.088	1.123	1.161	1.202	1.246	1.293	1.343
	3	1.000	1.024	1.054	1.086	1.118	1.154	1.195	1.237	1.282	1.330
	4	1.000	1.027	1.055	1.083	1.115	1.150	1.187	1.227	1.270	1.316
urban, not finished secondary school	**0**	1.000	1.028	1.059	1.093	1.128	1.166	1.207	1.250	1.296	1.346
	1	1.000	1.025	1.057	1.086	1.119	1.154	1.191	1.231	1.275	1.321
	2	1.000	1.028	1.060	1.093	1.129	1.168	1.209	1.253	1.300	1.351
	3	1.000	1.027	1.059	1.092	1.123	1.161	1.202	1.244	1.289	1.338
	4	1.000	1.029	1.058	1.087	1.120	1.155	1.193	1.233	1.277	1.323
urban, secondary or higher educated	**0**	1.000	1.031	1.070	1.109	1.149	1.192	1.237	1.284	1.335	1.389
	1	1.000	1.027	1.064	1.088	1.116	1.146	1.177	1.211	1.247	1.286
	2	1.000	1.034	1.075	1.114	1.156	1.200	1.248	1.298	1.352	1.410
	3	1.000	1.030	1.068	1.106	1.131	1.172	1.216	1.259	1.305	1.354
	4	1.000	1.021	1.050	1.075	1.105	1.137	1.170	1.205	1.243	1.284

where high skilled labor is relatively scarce, whereas poor and unskilled households are better off in the high investment scenarios. These households, who start from a very low endowment with human capital, accumulate relatively more human capital and thus benefit more from higher school provision. Scenario 4 is the most beneficial for unskilled and poor households. This scenario combines high schooling provision and the outside option of child labor and thus allows households to accumulate more human capital while still earning income from child labor as well.

5.6.2. Robustness

As we have a very high degree of disaggregation both in production sectors and production factors, it is very important to test whether the results are robust with respect to the assumed elasticities both in the production function as well as in the Armington aggregation. In order to test this robustness, we have run a series of 1000 simulations in which we have drawn these elasticities randomly from the intervals shown in table 5.8.[10] Given the dynamic structure of the model as well as the high degree of disaggregation these simulations produce a high amount of data. We focus here on presenting the results for the macroeconomic aggregates. However, all results presented above lie within a 95% confidence interval based on all 1000 simulations.

Table 5.8 shows the intervals from which the elasticities have been drawn. It is obvious that we include a very high variation for the elasticities. We generate the elasticities using a random number generator, we cannot allow negative numbers and in the Armington function elasticities of 0 are not possible, either. Apart from these limitations we allow any combination of elasticities.

Table 5.8.: Distribution of elasticities

Elasticity	Value in simulations	Min in Robustness checks	Max in Robustness checks
Production function			
σ_{cap}	0	0.0	1.5
σ_{va}	0.5	0.0	2.0
σ_{lab}	0.5	0.0	2.0
σ_{hskl}	1	0.2	3.0
σ_{lskl}	2	0.5	5.0
σ_{non}	8	2.0	16.0
Armington aggregation			
ρ^s	0.2 - 2.0	0.00001	6.0
ρ^t	0.2 - 4.0	0.00001	6.0

Table 5.9 presents the relative deviation between our results reported in the respective section and the maximum and minimum values retrieved for the respective variables in the robustness checks. We calculate the deviation of the maximum (minimum) value from the value reported in our result-section relative to the result value itself. Most results

[10] Jensen & Tarr [2011] follow a comparable procedure for robustness tests.

spread only within an interval of less than 1% around the results originally presented above. All results for the macro-economic aggregates lie well within a 95% confidence band. Thus, we consider our results very robust with respect to the elasticity parameters.

The results for the Hicks equivalent welfare measure are slightly less robust than those for GDP and educational production. GDP and educational production produce fairly robust results, especially in the case of educational production where the scenarios differ substantially, the deviation may be considered insignificant.

Table 5.9.: Relative deviation of results from maximum and minimum in robustness checks

Variable	Indicator	Scenario	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
GDP	Max-dev	1	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.003	0.004
		2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
		3	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002
		4	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.004
	Min-dev	1	0.000	0.000	0.000	0.001	0.001	0.002	0.004	0.005	0.009	0.012
		2	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.006	0.009	0.013
		3	0.000	0.000	0.000	0.001	0.003	0.003	0.004	0.004	0.006	0.009
		4	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.005	0.009	0.013
Welfare	Max-dev	1	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.004
		2	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.005	0.006
		3	0.000	0.001	0.001	0.002	0.003	0.003	0.004	0.005	0.005	0.006
		4	0.000	0.004	0.003	0.002	0.003	0.004	0.004	0.005	0.006	0.007
	Min-dev	1	0.000	0.002	0.004	0.005	0.007	0.009	0.010	0.012	0.014	0.016
		2	0.000	0.002	0.003	0.007	0.010	0.013	0.015	0.019	0.024	0.030
		3	0.000	0.003	0.007	0.011	0.012	0.013	0.015	0.017	0.018	0.021
		4	0.000	0.005	0.007	0.011	0.014	0.016	0.018	0.020	0.022	0.024
Educational production	Max-dev	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		4	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
	Min-dev	1	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001
		2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		3	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
		4	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001

On the macroeconomic level, we find noteworthy variance only for price variables not for quantity variables. Hence, the changes in the substitutability between factors or between markets are absorbed by prices and have only marginal real effects. Prices in CGE models in general only reflect relative price evolution compared to a numéraire good (the trade basket's price on world markets in our case). Thus, prices in general should be interpreted with some caution. We do not interpret the price results here and the quantity effects shown above seem to be quite robust concerning the choice of elasticities. At one point in our model a price effect is crucial, though: the price for human capital influences households' demand for education. However, the price for education is (also in the robustness simulations) closely linked to the price for human capital and thus, the demand-increasing effect of a specifically high price of human capital is compensated by a demand-decreasing effect of the price for education. The educational production is thus not affected crucially as shown in table 5.9.

We see from our robustness checks that the aggregate variable results are quite robust with respect to massive changes in the elasticities in production and trade. However, on the sectoral level, we find some sectors which are very sensitive to the elasticity set, namely coffee, fishing, hunting/forestry and private services. As the anomalies also occur in the base year before any schooling policy is in place and are also present in all different counterfactuals, we are sure that this result is not specific to our policy simulations and thus the other results for the different scenarios are still valid. However, the non-robustness of disaggregate results on the sectoral level sheds light on the fact that more reliable information on sector specific elasticities would be a valuable improvement of most developing country CGEs with high degrees of disaggregation.

Table 5.10.: Summary sectoral robustness

Sector	95%-Criterion	5%-Deviation-Criterion
MAIZE	+	(+)
PADDY	+	-
OSTF	+	-
WHEAT	+	-
BEANS	+	-
CEREA	+	+
OILSE	+	+
COTTO	+	-
COFFE	-	-
TOBAC	+	-
TEAGR	+	-
CASHE	+	-
SISAL	+	-
SUGAR	+	-
OFRVE	+	-
OCROP	+	-
LIVES	+	-
FISHI	-	(+)
HUFOR	-	-
MININ	+	-
MEATD	+	-
GRAIN	+	-
PFOOD	+	+
BEVER	+	(+)
CLOTH	+	-
WOODP	+	-
CHEMI	+	-
RUPLA	+	-
GLASS	+	(+)
METAL	+	-
EQUIP	+	-
UTILI	+	+
CONST	+	+
TRADE	+	+
TRANS	+	-
ESTAT	+	-
ADMIN	+	-
PRIVS	-	-

Table 5.10 summarizes the sectoral robustness results. We report two criteria for robustness here: Whether or not the result of our simulations with the initital elasticity set lies within a 95% confidence interval computed based on the robustness simulations and whether our result does not deviate by more than 5% from the minimum and maximum values found in the robustness simulations. A "+" in table 5.10 indicates that the criterion is fulfilled for the respective sector in all scenarios, a "(+)" means that it is fulfilled

in three out of the four scenarios.

5.7. Conclusion and policy implications

We have shown how human capital accumulation can be modeled in a detailed manner in a developing country CGE model. By disaggregating skilled and semi-skilled labor into the raw labor force and the human capital and by modeling schooling, i.e. educational production, explicitly, we add a number of aspects that have so far been treated only indirectly or left out completely in comparable studies. We are able to model the endogenous choice of skill levels, educational demand, opportunity costs of sending children to school and the effects of an increased pupil-teacher ratio.

Using our model to analyze different policy options we confirm a growth and welfare increasing effect from school investments, even though it is rather small, like other authors have shown before. However, a noteworthy effect on macro-economic variables is only reached if increased enrollment is accompanied by both, higher schooling investment and a higher employment of teachers. If both are in place, the majority of children are endogenously sent to school even if mandatory schooling is not enforced effectively. The opposite is true for mandatory schooling without the required resources i.e. only increasing the size of classes. In this case we do not find a growth or welfare effect as the positive effect from human capital accumulation is compensated by a negative effect from reduced childrens' production and income as well as reduced pass-rates.

In this study we used a dataset for Tanzania for 2001, which provided enough information on labor and skill disaggregation. However, it could be used with more recent datasets as well as other countries, if datasets with enough details were available. It could then be used to simulate policies beforehand.

The schooling investment policies are especially beneficial for poor households and those with very low skills. These households benefit overproportionally from increased human capital accumulation and thus receive higher income.

We confirm, in accordance with other authors, that capital as well as land might act as constraining factor on the growth effect from increased human capital. Even with the assumption of increasing productivity of both capital and land, we find land to be relatively scarce and thus being paid higher rents compared to all labor classes' wages. This indicates that the new high and semi skilled labor could produce even more if it were equipped with more land or if capital and land productivity would rise.

In a very elaborate robustness testing procedure we are able to show that a different choice of elasticities has only a minor impact on quantity variables on the aggregate level. The results presented above are robust across a very high number of iterations with different elasticities. Contrastingly, the elasticity set has a strong influence on price variables and on the sectoral results. This highlights the fact that, if price variables and wages are interpreted in a CGE study, more emphasis should be placed on the estimation of appropriate sectoral elasticities.

D. Appendix

D.1. Data description and parameters

Table 5.11.: Household and labor classes

Abbreviation	Description	Classification
Households		
HRBFPL	Rural, below food poverty line	rural, poor
HRFBPL	Rural, above food, below basic needs poverty line	rural, poor
HRNFPS	Rural, HH head has not finished primary school	rural, non-poor, low-skilled
HRNFSS	Rural, HH head has not finished secondary school	rural, non-poor, low-skilled
HRSECP	Rural, HH head has not finished primary school	rural, non-poor, high-skilled
HUBFPL	Urban, below food poverty line	Urban, poor
HUFBPL	Urban, above food, below basic needs poverty line	Urban, poor
HUNFPS	Urban, HH head has not finished primary school	Urban, non-poor, low-skilled
HUNFSS	Urban, HH head has not finished secondary school	Urban, non-poor, low-skilled
HUSECP	Urban, HH head has not finished primary school	Urban, non-poor, high-skilled
Labor Classes		
FSUB	Subsistence labor	Unskilled
CHILD	Child labor	Unskilled
LNON	Adult, no education	Unskilled
LNFP	Adult, not finished primary school	Low-skilled
LNFS	Adult, not finished secondary school	Low-skilled
LSEC	Adult, secondary or higher education	High-skilled

Table 5.12.: Production sectors

Index	Sector	Description	Classification
1	MAIZE	Maize	Agricultural, high share home consumption, tradeable
2	PADDY	Paddy rice	Agricultural, medium share home consumption, tradeable
3	OSTF	Other staple food	Agricultural, high share home consumption, tradeable
4	WHEAT	Wheat	Agricultural, low share home consumption, tradeable
5	BEANS	Beans	Agricultural, medium share home consumption, tradeable
6	CEREA	Cereals	Agricultural, medium share home consumption, tradeable
7	OILSE	Oil seed	Agricultural, medium share home consumption, tradeable
8	COTTO	Cotton	Agricultural, no home consumption, tradeable
9	COFFE	Coffee	Agricultural, low share home consumption, tradeable
10	TOBAC	Tobacco	Agricultural, no home consumption, tradeable
11	TEAGR	Tea growing	Agricultural, low share home consumption, tradeable
12	CASHE	Cashew nuts	Agricultural, no home consumption, tradeable
13	SISAL	Sisal	Agricultural, no home consumption, non tradeable
14	SUGAR	Sugar	Agricultural, low share home consumption, tradeable
15	OFRVE	Other fruit and vegetables	Agricultural, medium share home consumption, tradeable
16	OCROP	Other crops	Agricultural, medium share home consumption, tradeable
17	LIVES	Livestock	Agricultural, medium share home consumption, tradeable
18	FISHI	Fishing	Agricultural, low share home consumption, tradeable
19	HUFOR	Hunting and forestry	Agricultural, medium share home consumption, tradeable
20	MININ	Mining	Manufacturing, no home consumption, tradeable
21	MEATD	Meat and dairy products	Manufacturing, medium share home consumption, tradeable
22	GRAIN	Grain milling	Manufacturing, no home consumption, tradeable
23	PFOOD	Processed food	Manufacturing, low share home consumption, tradeable
24	BEVER	Beverages	Manufacturing, low share home consumption, tradeable
25	CLOTH	Clothing	Manufacturing, no home consumption, tradeable
26	WOODP	Wood and paper	Manufacturing, no home consumption, tradeable
27	CHEMI	Chemistry, fertilizer and refinery	Manufacturing, no home consumption, tradeable
28	RUPLA	Rubber and plastic	Manufacturing, no home consumption, tradeable
29	GLASS	Glass	Manufacturing, no home consumption, tradeable
30	METAL	Metallurgy	Manufacturing, no home consumption, tradeable
31	EQUIP	Equipment	Manufacturing, no home consumption, tradeable
32	UTILI	Utilities	Manufacturing, no home consumption, non tradeable
33	CONST	Construction	Manufacturing, no home consumption, non tradeable
34	TRADE	Trade	Services, no home consumption, non tradeable
35	TRANS	Transport	Services, no home consumption, tradeable
36	ESTAT	Real estate	Services, medium share home consumption, non tradeable
37	ADMIN	Public services, administration	Services, no home consumption, tradeable
38	PRIVS	Other private services	Services, no home consumption, tradeable

Table 5.13.: Input coefficients in %

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	MAIZE	5.47																7.97		
2	PADDY		22.67																	
3	OSTF			2.95														0.75		
4	WHEAT				5.91															
5	BEAN					12.78														
6	CERE						8.63											0.72		
7	OILS							6.23												
8	COT								2.55											
9	COF									4.20										
10	TOBAC										11.66									
11	TEA											4.42								
12	CASHE												1.35							
13	SISAL													17.14						
14	SUGAR														18.25					
15	OFRVE															2.12				
16	OCROP																1.51			0.10
17	LIVES									9.30						0.31	0.43	0.36		
18	FISH																		0.07	
19	HUFOR																	0.21	1.66	2.38
20	MIN																		0.49	
21	MEAT																			
22	GRAIN																			
23	PFOOD																	0.71		
24	BEVER																			
25	CLOTH	0.08	0.67	1.97	7.07	0.26	0.85	0.38	5.66		1.76		1.16	0.83		0.01		0.04	1.63	
26	WOODP	0.08	0.26	0.05	0.17	0.16	0.03	0.10	0.57		0.69	0.11	0.05			0.07	0.06	0.10		
27	CHEMI		0.13	0.06	9.97	0.05	8.99	0.03	9.39	5.70	8.21	14.89	3.92	4.10	0.64	0.22	0.22	0.00	1.28	0.04
28	RUPLA					0.02					0.62	0.48								0.01
29	GLASS																			
30	METAL	0.24	1.66	1.27	0.81	0.14	0.75	0.36	4.06	3.35	1.61	0.57	0.60		0.04	0.55	5.05	0.23	0.28	0.17
31	EQUIP	0.00	0.02	0.00	0.10		0.03	0.02	0.16	0.02				9.80					1.44	
32	UTILI	0.02	0.03	0.05	0.48	0.05	0.10	0.15	0.09	0.96	0.23	9.29	0.10	17.89	0.95	0.05	0.13	0.24	0.04	0.08
33	CONST	0.16	0.14	0.02	0.09		0.04	0.03	0.31	0.42	0.44	0.46	0.09					0.31		0.06
34	TRADE	4.69	2.60	1.61	6.30	1.54	5.09	1.55	21.48	7.59	9.02	12.11	1.74	4.45	1.81	1.58	1.56	2.55	2.50	1.44
35	TRANS	0.98	1.99	1.13	2.14	0.57	0.34	0.51	5.27	2.16	10.65	3.58	1.04	2.41	2.81	0.44	0.81	1.28	0.02	1.34
36	HOUSE	0.08	0.04	0.02	0.17	0.04	0.13	0.06	0.21	0.14	0.34	0.07	0.20	0.24	0.05	0.01	0.04	0.06	0.06	0.10
37	ADMIN																	0.01		0.08
38	SERV	0.05	0.03	0.02	0.34	0.02	0.19	0.08	0.26	0.00	0.00	0.05	0.00	0.00	0.06	0.03	0.03	0.00	0.00	1.82
	FSUB	60.09	16.10	61.83	3.60	25.69	9.12	24.52		5.53		0.84			1.14	38.31	40.02	15.62	5.65	55.08
	CHILD	0.14	0.12	0.36			0.34	0.51	2.60				0.89			0.70	0.97	3.32		
	LNON	2.29	2.09	2.47		4.07	6.14	5.12	2.02	2.95	3.37		7.72	8.20		2.78	4.12	5.03	7.99	1.04
	LNFP	2.99	5.87	3.23		5.48	6.46	7.47	7.22	6.71	6.92	26.50	11.60	4.74	37.60	4.51	6.32	5.45	14.12	
	LNFS	9.14	18.88	8.39	31.42	19.95	19.61	19.96	13.05	20.31	15.79		24.76	7.15		20.44	13.41	19.90	20.66	17.23
	LSEC	0.18	0.60	0.14		0.27	0.32	0.16	0.09	0.43	1.35					0.72	0.30	1.31		0.78
	CAPAG	9.25	18.19	10.05	21.91	20.21	22.91	22.92	17.28	21.05	19.01	18.53	31.26	15.00	25.33	18.98	17.48	23.63	29.42	12.71
	CNAG																			
	LAND	3.96	7.79	4.31	9.39	8.66	9.82	9.82	7.40	9.02	8.15	7.94	13.40	6.43	10.85	8.13	7.49	10.12	12.60	5.44
	VAT	0.09	0.12	0.06	0.11	0.06	0.12	0.04	0.33	0.16	0.18	0.18	0.12	0.27	0.47	0.05	0.05	0.09	0.10	0.11

		20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1	MAIZE			30.74	1.18	4.79													0.00	
2	PADDY			39.29															0.05	0.16
3	OSTF			7.13	0.04	0.25													0.02	0.71
4	WHEAT			5.81	0.45	0.92													0.01	
5	BEAN	0.11																	0.40	0.86
6	CERE			2.80	0.24	1.95													0.16	
7	OIL				4.63														0.07	0.02
8	COT						15.72			0.01										
9	COF				0.43															0.03
10	TOBAC					16.13														
11	TEA																			
12	CASHE				0.01	0.06														0.00
13	SISAL						3.68													
14	SUGAR				43.40	0.94														
15	OFRVE				0.43	3.86				0.02									0.01	1.58
16	OCROP				0.05														0.03	1.23
17	LIVES		35.48		0.24		0.20												0.26	2.58
18	FISH				0.04					0.01										1.08
19	HUFOR	0.15	0.10		0.03	1.37	0.03	14.56		1.12					0.33				0.00	0.05
20	MIN	1.57	0.28		0.16	0.00			19.64	11.53	9.28	1.71			8.48			1.40	0.00	0.00
21	MEAT		0.00		0.00		0.00													0.06
22	GRAIN	0.07			2.31	6.99														0.38
23	PFOOD				0.21	3.56														0.61
24	BEVER				0.90	3.92													0.11	2.63
25	CLOTH	0.07		0.00	0.00	0.59	4.10	0.03		0.16	0.30	1.18		0.04						0.04
26	WOODP	0.12	0.00	0.13	0.72	0.44	0.52	17.62	1.69	0.24	3.79	0.99	0.23	1.35	5.51	0.39	0.95	0.30	2.20	2.43
27	CHEMI	1.07	0.01		0.18	0.80	0.54	1.06	30.05	0.58	12.63	0.47	0.42	8.13	0.11	0.02	0.39		0.00	1.49
28	RUPLA	0.10	0.06	0.00	0.19	0.52	0.05	0.06	0.21	31.65	0.05	1.96	3.26	0.11	0.05	0.02	0.52	0.00	0.01	0.27
29	GLASS	0.32			0.02	0.53			0.31	0.06	3.83		5.11	0.09	10.78				0.09	0.18
30	METAL	0.35			0.03	0.08	0.01	0.10	1.27	1.06		41.68	16.78	0.07	8.64		0.27		0.02	0.86
31	EQUIP	1.00	2.17										24.62	3.20	3.80	0.49	4.69	0.56	1.68	3.19
32	UTILI	3.44	0.08	1.02	1.16	1.75	7.37	6.10	2.63	10.52	23.62	6.91	0.81	5.64	0.21	0.38	0.48	0.06	0.14	2.11
33	CONST	0.48	0.02	3.70	1.01	1.05	2.28	1.76	1.78	1.26	2.00	2.14	1.05	2.25	8.08	0.79	1.08	6.37	1.38	0.95
34	TRADE	1.45	7.53	0.91	3.08	6.48	6.15	6.08	5.29	4.41	6.87	8.42	4.14	6.64	3.07	1.27	3.04	0.56	1.67	6.72
35	TRANS	1.36	0.05	0.12	1.18	3.27	1.38	1.51	3.29	2.62	2.40	1.50	1.46	5.12	2.48	7.24	5.25	0.37	1.80	4.28
36	ESTAT	0.69	0.07	0.04	0.87	0.64	0.55	0.82	0.72	0.84	0.53	0.59	0.37	3.16	1.02	2.62	4.16	61.61	1.12	6.34
37	ADMIN													0.27	0.65	1.70	2.82	2.71	53.93	0.92
38	SER	1.46	0.30	0.23	1.02	0.97	1.51	1.31	1.37	1.54	0.77	0.82	0.61	2.69	2.03	6.64	11.96	3.72	5.06	7.99
	FSUB		46.91		5.90	5.01												18.34		
	CHILD	0.07		0.02			0.09	0.01							0.09	0.01				0.03
	LNON	0.05	0.01	0.17	0.20		0.66	0.70			0.10	0.36		0.66	0.63	0.22	0.06		0.08	0.43
	LNFP	0.06	0.08	0.46	0.22	0.01	2.69	0.50		0.09	0.13	0.94	0.89	0.46	3.28	0.58	0.19		0.52	1.26
	LNFS	1.18	0.33	4.73	1.96	0.45	20.07	7.91	17.84	4.91	6.27	3.28	1.33	5.15	20.81	3.33	3.13	0.15	6.90	8.10
	LSEC	0.15	0.10		2.60	6.21	5.67	2.23	0.39	1.98	1.21	2.72	1.53	6.15	5.39	2.05	4.78	1.11	20.97	4.18
	CAPAG																			
	CNAG	84.61	6.30	1.81	24.77	26.19	26.43	37.40	13.11	25.12	25.97	24.03	37.21	48.66	14.27	72.05	55.88	2.68	1.21	35.82
	LAND																			
	VAT	0.09	0.12	0.28	0.12	0.25	0.30	0.25	0.42	0.25	0.25	0.30	0.18	0.16	0.28	0.20	0.35	0.06	0.11	0.45

Table 5.14.: Armington elasticities

elasticity / sector	ρ_i^s Import substitution	ρ_i^t Export transformation	τ_i Home-market transformation
MAIZE	2.0	2.0	4.0
PADDY	2.0	2.0	4.0
OSTF	2.0	2.0	4.0
WHEAT	2.0	2.0	2.0
BEANS	2.0	2.0	4.0
CEREA	2.0	2.0	2.0
OILSE	2.0	2.0	4.0
COTTO	1.5	4.0	2.0
COFFE	1.5	4.0	2.0
TOBAC	1.5	4.0	2.0
TEAGR	1.5	4.0	2.0
CASHE	1.5	4.0	2.0
SISAL	1.5	4.0	2.0
SUGAR	1.5	4.0	2.0
OFRVE	1.5	4.0	2.0
OCROP	1.5	4.0	2.0
LIVES	0.5	0.5	4.0
FISHI	0.5	0.5	4.0
HUFOR	0.5	0.5	4.0
MININ	1.5	4.0	0.1
MEATD	0.5	0.5	4.0
GRAIN	1.5	4.0	2.0
PFOOD	1.5	1.5	2.0
BEVER	1.5	1.5	2.0
CLOTH	1.5	1.5	0.5
WOODP	1.5	1.5	0.5
CHEMI	0.2	0.2	0.2
RUPLA	1.0	1.0	0.2
GLASS	1.0	1.0	0.2
METAL	1.0	1.0	0.2
EQUIP	1.0	1.0	0.2
UTILI	1.0	1.0	0.2
CONST	1.0	1.0	0.2
TRADE	0.2	0.2	0.1
TRANS	1.0	1.0	0.1
ESTAT	0.2	0.2	0.2
ADMIN	0.2	0.2	0.2
PRIVS	0.2	0.2	0.2

Table 5.15.: Households' consumption preferences

Good \ HH	HRBFPL	HRFBPL	HRNOED	HRNFPS	HRNFSS	HRSECP	HUBFPL	HUFBPL	HUNOED	HUNFPS	HUNFSS	HUSECP
MAIZE	11.04	13.36	10.84	10.11	9.59	4.00	6.33	4.48	5.92	3.96	3.53	1.34
PADDY	1.74	1.26	2.18	2.12	1.59	0.47	0.89	0.70	0.59	0.68	0.67	0.21
OSTF	9.69	7.74	7.55	5.96	5.22	1.82	3.72	3.20	2.57	2.61	1.66	0.95
WHEAT	0.03	0.06	0.04	0.04	0.06	0.03	0.04	0.02	0.00	0.03	0.37	0.02
BEANS	2.85	2.73	2.55	2.69	2.55	1.70	3.04	2.48	2.47	2.07	1.64	1.15
CEREA	0.64	0.16	0.05	0.06	0.06	0.09	0.07	0.02	0.03	0.04	0.02	0.01
OILSE	1.06	1.42	1.77	1.37	1.44	0.65	1.66	1.42	1.95	1.49	1.12	0.70
COTTO												
COFFE	0.03	0.03	0.01	0.39	0.04	0.01	0.00	0.00	0.01	0.01	0.03	0.01
TOBAC												
TEAGR	0.18	0.20	0.25	0.29	0.29	0.44	0.42	0.42	0.40	0.37	0.35	0.31
CASHE												
SISAL												
SUGAR	0.19	0.21	0.24	0.23	0.18	0.05	0.13	0.08	0.09	0.14	0.04	0.02
OFRVE	6.93	7.11	6.59	6.49	6.93	4.93	6.55	7.76	6.40	7.87	6.13	5.19
OCROP	1.10	1.25	1.35	0.85	0.78	0.21	0.65	0.61	0.62	0.69	0.33	0.24
LIVES	2.43	2.67	2.94	2.12	2.24	2.21	1.03	0.68	1.18	0.98	1.07	1.39
FISHI	4.66	3.88	3.36	4.09	3.62	2.94	5.91	4.12	4.15	4.71	2.95	2.42
HUFOR	3.72	3.77	3.80	3.84	3.30	2.81	3.93	4.12	4.81	3.88	3.30	2.15
MININ												
MEATD	4.74	5.13	5.01	5.34	4.11	6.27	4.05	5.21	4.73	4.93	4.46	4.83
GRAIN	8.90	7.47	7.77	7.24	7.93	7.35	11.52	13.18	11.54	11.20	8.98	7.34
PFOOD	4.45	4.91	6.02	6.24	6.39	7.67	9.61	10.06	9.90	9.16	7.75	7.14
BEVER	1.35	1.45	1.92	2.30	2.80	2.66	1.75	1.81	2.20	2.65	3.13	3.65
CLOTH	7.55	6.64	8.08	7.36	6.81	4.78	7.44	5.01	4.49	6.86	6.04	7.13
WOODP	0.33	0.16	0.43	0.50	0.46	0.64	0.36	0.39	0.38	0.29	0.59	0.69
CHEMI	4.68	3.87	3.92	6.72	3.98	9.17	5.80	4.60	5.53	5.48	5.11	6.05
RUPLA	0.75	0.82	0.74	0.63	0.94	0.74	1.13	1.82	0.87	0.77	0.97	0.92
GLASS	0.15	0.10	0.12	0.21	0.17	0.10	0.31	0.27	0.13	0.17	0.26	0.43
METAL	0.93	0.72	0.72	1.01	0.90	0.82	1.07	0.54	0.42	0.64	0.62	0.78
EQUIP	0.60	0.25	0.41	1.17	0.71	0.20	4.24	0.73	0.18	0.44	0.38	0.66
UTILI	0.46	0.51	0.90	0.83	0.71	0.51	1.19	0.81	0.92	1.10	0.92	1.30
CONST												
TRADE												
TRANS	0.95	0.75	0.48	1.10	1.24	2.47	2.04	1.96	1.69	2.78	3.38	4.74
ESTAT	8.42	7.67	7.93	8.27	8.34	6.73	8.41	7.87	7.76	7.83	7.43	7.18
ADMIN	0.51	0.33	0.22	0.66	0.54	0.49	0.29	0.71	0.25	0.75	0.76	2.42
PRIVS	2.45	2.52	2.87	3.98	4.16	4.56	2.92	3.71	8.49	5.32	7.44	8.95

Table 5.16.: Households' income shares (in %)

HH / Source	HRBFPL	HRFBPL	HRNOED	HRNFPS	HRNFSS	HRSECP	HUBFPL	HUFBPL	HUNOED	HUNFPS	HUNFSS	HUSECP
FSUB	43.53	45.44	51.77	42.51	22.75	6.86	5.76	4.39	7.21	7.66	6.84	10.44
LCHILD	0.31	0.22	0.78	0.30	0.15	0.02	0.13	0.59	0.45	0.21	0.20	0.51
LNON	4.88	4.56	9.33	0.60	0.21	0.03	3.29	1.40	8.28	0.36	0.08	0.17
LNFP	7.24	5.38	0.56	20.17	0.41	0.20	6.60	4.42	0.70	28.73	0.26	0.13
LNFS	7.65	8.26	2.77	6.10	24.25	2.13	14.04	11.50	6.52	6.27	33.90	5.14
LSEC	0.66	0.85	0.02	0.09	0.18	34.78	2.50	3.40	0.47	0.51	0.88	56.23
CAPAG	22.14	19.71	16.82	15.67	8.45	2.00	7.16	1.95	1.93	2.38	1.57	1.79
CAPNAG	3.09	6.40	6.08	3.84	35.55	39.84	56.36	71.10	64.84	46.16	49.11	7.26
LAND	9.45	8.42	6.97	6.60	3.78	0.96	3.47	0.96	0.92	1.11	0.71	0.74
GOV	1.04	0.75	1.24	1.09	0.77	0.69	0.71	0.28	0.84	0.60	0.51	0.42
ROW			3.66	3.03	3.50	12.47			7.85	6.01	5.95	17.17
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

D.2. Model code listing

**Model code documentation
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6. Concluding remarks

This thesis contributes in various dimensions to the state of the development economics literature. It provides important advancements in the fields of methodology and modeling, paired with equally enriching contributions to the area of development policy. Since the thesis comprises four papers on the aforementioned topics, a number of general finalizing conclusions will now be derived from the presented analyses.

In the field of CGE modeling, this thesis presents two static and one recursive-dynamic model implementations based on the structure of IFPRI datasets and written as mixed complementarity problems in MPSGE modeling syntax. Despite the pre-existing presence of an MPSGE version of the standard IFPRI model, the applications outlined here constitute possible enhancements, especially in regards to the government agent, the inclusion of proportional direct taxation and household savings, and the disaggregation of private and public capital. To the author's knowledge, an MCP/MPSGE implementation of a recursive-dynamic model based on the IFPRI data structure has not been previously available.

The aid model in chapter two provides a very detailed implementation of governmental behavior. It sets a distinction between different public expenditure positions such as public investment, transfers, subsidies to enterprises and public recurrent expenditure. In addition, it includes (household-specific) proportional income taxation and income-proportionality in private savings. Public and private investments are separated to allow for different investment good bundles, effectuating in varied outcomes for public and private investment, respectively. Unlike earlier aid-focused models, the model here covers home consumed agricultural production and its distinct features, as well as sector-specific factors.

The aid model has been already employed within a policy consultancy project at the Amsterdam Institute for International Development. The model was utilized for judging the probability of Dutch Disease effects from budgetary support in the special Zambian circumstances. The flexible model setup, together with the detailed government account, opens up a number of possible applications in the area of policy planning.

The infrastructure model in chapter three develops an explicit link between public investment in roads, the availability of road transport and the trade and transport margins. Thus, it establishes a completely different, more realistic and detailed approach to modeling road network improvements. It remains in a stark contrast to the general public capital stock models since infrastructure is regarded as a concrete means of transport. Improved or new road networks provide an alternative for transport services and therefore reduce the requirements for labor and capital in transportation. As a result, we discover a direct relationship between the transport margin and the availability of roads, which is often established in the theoretical papers but has not yet been transferred to the CGE world. This transport margin approach is documented in a small theoretical model which can be solved analytically. The procedure is then integrated into a full detail real world CGE model. The model includes operation and maintenance costs and compares different assumptions concerning the ownership of the public capital and consequently the reception of returns to this capital stock.

The recursive-dynamic education model in chapter five combines features from different models in the relevant literature while adding a considerable number of new features. Aside from having a higher degree of disaggregation with respect to the number of sectors, households and factors included in the analysis, it also directly models the educational process itself. The model introduces human capital as an asset which is produced (in formal schooling), accumulated by private households, and eventually demanded in the production of goods and services. This is a new approach in the respective strand of the model-based literature on education and it is a clear progress in this area of modeling. The model explicitly includes the three-phase Tanzanian schooling system and the educational requirements for the respective labor classes. It accounts for the costs of the educational process in terms of staff, buildings and foregone labor force. Most importantly, the model incorporates explicitly the households' decisions on the allocation of childrens' time for work versus education. It further introduces some elements of forward-looking behavior with respect to educational choices into the recursive-dynamic setup which has myopic agents in general. The simulations hence provide results for endogenous educational attainment and endogenous enrollment. The modeling of the alternative costs of education, i.e. the foregone earnings from child labor, grants an insight to the inter-temporal income dynamics of private households as reactions to the increased enrollment.

Particularly the last chapter contains very elaborate robustness checks. The robustness of the model results is explored by drawing all elasticity parameters from random distributions and running a very high number of repeated simulations. This procedure allows to compute confidence bands and reveals that the obtained results for quantity variables are very robust whereas price variables are rather sensitive with respect to changes in the elasticities. These findings show that the interpretation of price results should be considered with some caution and that more information on elasticities of substitution, both in production and in trade, is needed. Alike robustness testing techniques are generally available in the GAMS syntax but are rarely applied in CGE studies in the development economics literature. However, robustness checks and the calculation of confidence bands supply useful insights concerning the reliability of CGE results. Such a procedure ensures a cautious interpretation of the results and allows for a better assessment of real world effects. Furthermore, such sensitivity analyses may help to create a broader acceptance of CGEs in economic research.

Regarding the policy implications of the articles included in this thesis, each study has its merit in providing a disaggregate perspective on the analyzed problem. The papers put emphasis on the household-, factor- and sector-level results and demonstrate that a disaggregate perspective paired with an adequate detail in these aspects is an essential value in CGE modeling. In brief, only a detailed analysis and interpretation of the sectoral and factor-level results allow to explain the macro-level effects.

The analysis of aid effects and different spending strategies in chapter two confirms in accordance with the econometric literature that *Dutch Disease* is a legitimate concern and a serious problem for African countries. The size of the *Dutch Disease* effect, however, depends on the spending strategy of the receiving government which is a novel insight compared to other CGE studies. Investment-focused strategies induce much lower *Dutch Disease* effects than their consumption-focused counterparts. Nevertheless, Dutch Disease effects are stronger if production factors are completely mobile across sectors, whereas they are weaker if the main exporting sectors demand partly or completely sector-specific factors. The export contraction and real appreciation might be reduced if aid is invested in a way that fosters productivity as other authors have pointed out. However, we only find a complete reversal of the real appreciation if we assume a very high productivity response.

We ascertain that policy makers face a trade-off situation regarding the use of aid. An investment-focused strategy will increase productivity and foster growth in the medium run but it leads to lower immediate welfare effects. In addition, it can possibly bring about undesired distributional consequences if high-skilled wages rise or agricultural exports suffer. The first is a relative gain for richer households and the second is a relative loss for farmers and farm workers. This diagnosis might, to a certain extent, explain why in reality we often observe a shifting of budget components rather than a sole expansion of the investment budget after a positive shock of aid inflows into a certain country. It is probable that governments tend to choose a mixed spending strategy, especially if aid is given in a form of general budgetary support rather than program or project aid. Hence, the inclusion of different uses of aid is a contribution with regard to more realistic modeling.

The CGE analysis of infrastructure investment in chapter three confirms that an improved transport network has a positive impact on production and growth. A confirmation of the notion that a better access to markets will lead to a higher share of agricultural production being marketed could not be found. Nonetheless, households use their surplus income to buy non-agricultural marketed goods such that the importance of marketed goods grows in the consumption bundles.

In accordance with the first study, equally for infrastructure, quite substantially differing sectoral effects are discovered. While some sectors, especially in manufacturing, experience a boost in their production, other sectors, mainly in agriculture and services, have declining outputs. Therefore improved infrastructure might not be beneficial to all households. Those who are employed in the declining sectors and especially the land owners are worse off. A closer look at the distributional results, which is a specific feature of this model implementation, reveals that the effect on distribution strongly depends on the regional allocation of the public capital in infrastructure. If it is mainly located in rural areas (i.e. owned by rural households), the distributional outcome is positive, whereas the distributional outcome is pro-urban if the government redistributes the returns to the infrastructure through taxes. The model accounts for operation and maintenance cost and emphasize that these have to be included in policymakers' decisions. The disaggregation of infrastructure and other public capital provides new insights in the mechanisms at work and enhances the sectoral results as sectors have very different transport requirements.

For the infrastructure model the elasticity of the trade and transport margin with respect to changes in the road network density has been estimated from a cross-sectional dataset based on input-output data. This approach is developed further in the paper in chapter 4. Studies of the determinants of transport costs typically focus on distinct countries and infrastructure projects like the construction of the East German motorways after German reunification to give one example. Cross-country estimations are rare in the literature as an internationally comparable measure of transport costs is hard to find. Thus, based on country and case studies, it is not possible to draw definite conclusions on the effectiveness of road construction that would apply to all different country groups.

The article presented in chapter four develops and applies a new proxy for the transport costs which is available for a large number of countries. Based on aggregated input-output data, sectoral transport margins, i.e. the share of transportation in total production costs, were calculated. I established a panel dataset for sixty-four countries over three years and regress the transport margin on a number of possible determinants. The estimation generates some surprising results. The influence of the road network and most alike other determinants of transport costs, such as climate and urbanization, differs strongly across country groups and sectors. For the whole sample, I find that the transport network density, urbanization and population density have a strong influence on transport costs. A division of the sample into two groups of countries reveals that the estimated relationship for high-income countries is indeed not applicable for middle- and low-income countries. For these countries, the regression identifies corruption together with climate conditions as key factors for transport costs. In highly corrupt countries, the cost-reducing effect from additional roads disappears completely, at least as far as agricultural goods are concerned. It can be concluded that the positive experiences from industrial countries cannot be easily transferred to and implemented in the middle- and low-income states. Substantially different settings in these countries impair the efficiency of roads in transport cost reduction.

The analysis of educational investment in chapter five reveals that a positive outcome for production and welfare through increased supply of skilled labor is only possible if the increased enrollment does not come at the expense of class sizes and classroom double-shifting. Provided that enough teachers and schooling facilities are available, a high proportion of children is endogenously sent to school. In this case we observe high welfare and growth effects in the medium- to long-term, in combination with a relatively high short-term income effect, especially for the households with low-educated adults. The opposite holds true if enrollment is increased without providing the required resources. In this case we find a strong short-term negative effect on household incomes and a lower welfare and growth effect in the medium- and long-term for the uneducated households.

The educational model endogenizes the choice of the skill level as well as the time allocation to school attendance versus labor. The human capital produced by increased schooling might be transformed into low-skilled, medium-skilled or high-skilled labor, depending on the demand and price for these respective skill classes. Consistently across all scenarios, the model predicts a medium-term increase in medium-skilled workers employment and only later on an increase in high-skilled employment relative to the baseline without schooling investment. It is important to mention that a high proportion of the high-skilled labor professionals is employed in the public sector due to the need for additional teachers. Hence, the rest of the economy benefits from a higher supply of medium-skilled workers, whereas the public sector absorbs the additional high-skilled employees. These dynamic labor market effects as well as the detailed results for child labor supply go well beyond the state of the relevant literature and the respective models.

All of the investment strategies here-mentioned will only lead to noteworthy effects in the medium- to long-run. It takes time to build a road, educate a child or bring water to rural regions. In the short term most of the simulations presented here reveal the possibility of undesired adverse distributional effects. The direct effect from increased governmental spending mainly occurs in some distinct sectors, namely public administration and construction. Hence, the first round effect is mainly to the benefit of those employed in these sectors. Thus, a short-term compensation for rural and poor households might constitute a reasonable option, depending on the circumstances. This is of outmost importance in the case of schooling. Foregone household income due to educational attainment of the children is by no means negligible. We see that, if made possible in the model's assumptions, the endogenous enrollment covers only for more or less 60% instead of a 100% enrollment rate. Conclusively, compensation for foregone earnings from child labor could endogenously increase school attendance.

Nevertheless, providing sufficient resources for schooling and thus increasing the supply of skilled labor is not sufficient on its own. As shown in chapter four, a number of other factors might limit the productivity of the additionally available skilled labor. If capital and land are very scarce, or if their productivity cannot be increased, the higher share of skilled workers will not lead to substantial increases in production in result of the limited endowment with capital or land.

This last finding highlights the relevance of the first and second paper of this thesis that call for aid spending being channeled into programs that allow to increase the total factor productivity. A higher-skilled labor force needs highly productive capital and land in order to be of value for the economy. Thus, the most general conclusion from the different analyses summarized here is that an optimal use of developmental aid should combine investment and recurrent spending in a way that leads to a balanced productivity response for all relevant factors of production. If aid is used to finance roads, they will require maintenance and have to be built in the right regions for rural productivity to increase. A longer road built in the wrong place or not adequately maintained will not improve market access through lower transport costs for rural products. If aid is used to build schools, these will only help to increase the supply of skilled labor, provided that there are enough teachers employed. If the teachers are unavailable, a positive welfare effect is unlikely. Even if the supply of skilled labor rises, additional resources in form of the complementary factors of production, capital and land, are necessary to reach a higher level of production.

The results of this thesis, taken together with the lessons learned from the history of development cooperation, call for a cautious and balanced approach to development aid. A sound analysis of the circumstances and requirements of a specified developing country, or even better: a concrete region within the country, should precede the programs' planning. Instead of following a one-size-fits-all-approach, which was often the case in the past, the international aid agenda ought to be flexible enough to comply with the local requirements.

This thesis demonstrates the potential of the investment programs in question. However, cautious investment planning should consult other methods of economic research in addition to CGE results. I have demonstrated that the results always depend on the assumptions of the models. The reliability of a CGE model is dependent on the availability of reliable data and suitable model implementation. Thus, data work and the estimation of reliable elasticities could improve the reliability of CGE model results for developing countries in general. It needs to be highlighted that a sound understanding of the underlying models is crucial for interpreting and using the results as well. Taken with this pinch of salt, the obtained results provide many valuable and novel insights into the disaggregate effects of development policy. The respective models add to the state of the art in the outlined aspects and could be applied to a variety of other comparable problems and countries.

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Essen, 25. November 2011 H. Schürenberg-Frosch